**ORAU**

# COMPREHENSIVE

# RADIOLOGICAL SURVEY

# OF

# KRESS CREEK

# WEST CHICAGO AREA, ILLINOIS

## P. W. FRAME

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT

February 1984

COMPREHENSIVE
RADIOLOGICAL SURVEY
OF
KRESS CREEK
WEST CHICAGO AREA, ILLINOIS


Prepared for

Division of Fuel Cycle and Material Safety
U.S. Nuclear Regulatory Commission


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FOREWORD

A comprehensive radiological survey of Kress Creek has been performed by the Oak Ridge Associated Universities (ORAU) under contract to the United States Nuclear Regulatory Commission (NRC). Results of the survey are given in this report. This work is a continuation of effort by NRC to define the extent of radioactive contamination in Kress Creek and the West Branch of the DuPage River, downstream of the Kerr-McGee Rare Earths Facility in West Chicago, Illinois.

Radioactive contamination along Kress Creek and the West Branch of the DuPage River was first detected as a result of an aerial survey in 1977 and later verified by extensive surveys of the West Chicago area undertaken by Argonne National Laboratory in 1977 and 1978, and funded by the NRC. The results of these surveys, which were limited to measurements of surface exposures and dose rates, were reported in NUREG/CR-0413, published in September 1978. Additional surveys of the creek and river were made by the United States Environmental Protection Agency (EPA) (1980) and ORAU under NRC contract (1981). These surveys added to the overall information about the levels of contamination, but did not define the spatial distribution (i.e., depth in soil) of the contamination.

The comprehensive radiological survey reported in this document was specifically designed to determine not only current direct radiation levels, but also the depth distribution of contamination in the creek and river beds and in bank soil along the creek and river. This survey indicates that lands adjacent to the Kress Creek and West Branch of the DuPage River are contaminated with thorium and with daughter products of the thorium decay chain essentially in secular equilibrium. Soil contamination levels and direct levels of radiation were found to be relatively constant throughout the length of Kress Creek and to extend downstream along the West Branch of the DuPage River.

The average concentrations of total thorium (Th-232 + Th-228) at 1 meter from the edge of the creek at various depths were: 26.1 pCi/g (picocuries per gram) surface; and 18.7 pCi/g between 60 and 90 cm. The soil concentrations

decreased with increasing distance from the creek. The highest level of total thorium measured in a sample was 555 pCi/g, with a number of other samples exceeding 200 pCi/g. Many of the highest levels were detected in areas near the storm sewer outfall, and hence constitute a potential source of continuing contamination for locations further downstream. The baseline soil in this area contains an average of 1.6 pCi/g of naturally occuring thorium.

Direct levels of radiation measured at 1, 5, 10, and 25 meters from the edge of the creek and 1 meter above ground surface averaged 28, 25, 21, and 14 μR/h (microroentgens per hour) respectively. However, radiation levels greater than 100 μR/h were detected in several locations. Normal background radiation levels in this area averaged 8.6 μR/h.

The contamination levels found along the creek exceed the environmental standards promulgated by EPA under the authority of the Atomic Energy Act of 1954, as amended, for thorium processing wastes. The NRC is charged with implementation and enforcement of these standards. The contamination levels also exceed the identical standards established for cleanup of vicinity properties under Title I of the Uranium Mill Tailings Radiation Control Act of 1978, as amended. The EPA has stated that these standards are appropriate for cleanup of offsite vicinity properties. Therefore, cleanup of the radioactive contamination in the environment is required.

Accordingly, NRC intends to require Kerr-McGee to submit an action plan for cleanup of the contaminated areas. The plan will be subject to review and approval by the NRC staff. The action plan should establish the methods, scope, and timing of cleanup activities.

Copies of this report will be sent to property owners along Kress Creek.

Copies of this report are also available at no charge to members of the public at the West Chicago Public Library.

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INTRODUCTION

Between 1931 and 1973 a thorium ore processing facility was operated in West Chicago, IL, by Lindsay Light and Chemical Co., and successor owners. Initially, the principal activity at this site was extraction of thorium for use in the manufacture of gas mantles. Later operations included the recovery of rare earths also present in the ores. The resulting solid wastes were accumulated in two large piles on the plant site. Over the years, waste material was transported from these piles into a nearby storm sewer and drainage ditch and then to Kress Creek; this resulted in most of the contamination along the creek.

In 1974, the present owner of the facility, Kerr-McGee Corp., began cleanup activities to decommission the facility. At the request of the Nuclear Regulatory Commission (NRC), Argonne National Laboratory (ANL) conducted a radiological evaluation of thorium residues in the West Chicago area.[1] This study of the Kress Creek region consisted primarily of direct radiation measurements between the outfall of the sewer runoff and the juncture of Kress Creek with the DuPage River (West Branch). Radiation levels up to 150 μrem/h were reported for several locations up to 1 km downstream from the outfall. The ANL study estimated that at least 80% of the thorium waste in the creek was deposited in the upper one-third of its course between the sewer outfall and the DuPage River. A 1977 aerial radiological survey by EG&G confirmed the presence of thorium residues along the creek.[2] Soil and sediment samples collected in 1980 by Region V of the Environmental Protection Agency (EPA) indicated that distribution of the radioactive material was "much more extensive" than indicated by the ANL study.[3] EPA also identified the primary radionuclides in the waste as Th-232 and Th-228 in essentially secular equilibrium.

In July 1981 the Radiological Site Assessment Program of Oak Ridge Associated Universities, Oak Ridge, TN, conducted additional sampling and monitoring of Kress Creek. This survey was limited to the creek bed and the surface soils within several meters of the edge of the creek. The results generally confirmed the findings of earlier surveys.

At the request of the NRC Division of Fuel Cycle and Material Safety, a comprehensive radiological survey of Kress Creek was conducted December 6-20, 1982 and April 4-22, 1983 by the Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU), Oak Ridge, Tennessee. This report presents the findings of the survey.

A glossary of technical and nuclear terms and schematic representations of the naturally-occurring thorium and uranium radioactive decay series have been provided in Appendices A and B, respectively, to aid the reader in interpreting this report.

## SITE DESCRIPTION

Kress Creek in West Chicago, DuPage County, Illinois (see Figures 1, 2, and 3) originates on or near the Fermi National Accelerator Laboratory site. After leaving the Fermi site, the creek flows east under the Elgin, Joliet, and Eastern Railroad approximately 300 m south of Roosevelt Road. Immediately east of the railroad, the storm sewer from the Kerr-McGee facility, north of Roosevelt Road, empties into the creek. At this point Kress Creek changes direction, flowing toward the southeast until it joins the west branch of the DuPage River approximately 2 km downstream.

For the first 100 m south of the storm sewer outfall, Kress Creek flows through undeveloped property consisting mostly of trees and brush. The creek then passes through a subdivision between May and Joy Streets. Along its course through the subdivision, the creek expands to form Gunness Lake. South of Joy Street it flows through mostly open field until reaching Wilson Road. The banks along the 200 m of the creek immediately south of Wilson Road are covered with dense brush and trees. Beyond this, and until the creek reaches Illinois Route 59, the terrain is primarily open field although scattered

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brush and trees are found on the west bank. Further downstream, between Route 59 and the DuPage River, a forest preserve forms the east bank of the creek, and the back yards of several private residences form the west bank. The east bank of the south-flowing DuPage River is forest preserve, as is its west bank upstream of Kress Creek. The west bank of the river downstream of Kress Creek consists of scattered trees and vegetation, some marshy areas, and the back yards of a few residences.

The creek width varies from a typical 3 m up to 15 m in the case of Gunness Lake. The width of the DuPage River is a nearly constant 15 m. Under normal conditions the depth of the creek is approximately 30 cm, rarely becoming deeper than 60 cm. The DuPage River is only slightly deeper. Flooding of Kress Creek and the DuPage River is not uncommon. During the course of the survey, heavy rains caused the creek to overflow its banks by as much as 30 m. Flooding primarily, although not exclusively, occurs over the western banks of the creek and river.

## SURVEY PROCEDURES

### Objectives

The primary objectives of this survey were to determine the following along Kress Creek and properties adjacent to the creek:

1.  the direct radiation levels, and
2.  the radionuclide concentrations in soil and sediment.

### Plan

The survey plan included the following activities:

1.  Systematic exposure rate measurements 1 m above the surface at specified intervals along the banks of Kress Creek and the DuPage River.
2.  Dose rate and exposure rate measurements at the surface for each of the locations where measurements at 1 m were taken.

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3. Monitoring surface gamma radiation levels along the banks of Kress Creek and the DuPage River.

4. Measurement of radiation levels in boreholes drilled at the locations of the systematic direct radiation measurements, and at locations of elevated direct radiation levels.

5. Collection of soil samples from various depths in approximately 15% of the boreholes.

6. Collection of sediment core samples at specified intervals along Kress Creek and the DuPage River.

7. Collection of several residential well water samples from the vicinity of the creek.

8. Sampling and measurements at off-site locations to provide baseline and background data for comparison.

## Measurement of Direct Radiation

Kress Creek was divided into 50 m intervals between the DuPage River and a point approximately 100 m south of the Kerr-McGee storm sewer outfall. Permission could not be obtained from property owners to survey the area further north, i.e. immediately upstream and downstream of the outfall, or to survey two residential properties bordering Gunness Lake. One of these residential properties was immediately north of Joy Road on the east bank and the other was the second property north of Joy Road on the west bank. Fifty meter intervals were also established along the DuPage River, 200 m upstream and downstream of its juncture with Kress Creek.

At each interval, exposure rates were systematically measured both at the surface and 1 m above the surface, 1, 5, 10, and 25 m from the edge of the creek or river (measurement locations are identified in Figures 4, 5, 6, and 7). Exceptions were those areas for which permission was not granted by the property owners and those areas extending onto public roads. NaI(Tl) scintillation ratemeters, field-calibrated using a pressurized ionization chamber, were used to measure exposure rates.

Beta-gamma dose rates at 1 cm above the surface were measured at each location where the systematic exposure rates were measured. These

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measurements were performed using G-M detectors and scaler/ratemeters. To evalute contributions from both penetrating and nonpenetrating radiations, the measurements were made with the probes in both the open- and closed-shield configurations.

Using NaI(Tl) gamma scintillation ratemeters, walkover surface scans were performed to a minimum distance of 25 m on either side of Kress Creek and the DuPage River. General radiation levels and locations of significantly elevated levels were noted.

## Borehole Logging

Boreholes (15 cm diameter) were drilled with a portable motorized auger at locations of systematic direct radiation measurements. Boreholes were also drilled at selected areas of elevated direct radiation levels identified in the walkover surface scans. The former are referred to as systematic boreholes and the latter as biased boreholes. Figures 8, 9, 10, and 11 indicate the locations of both the systematic and biased boreholes. Whenever possible, boreholes were drilled to a depth of 1 m. A layer of rock, which prevented further drilling, was encountered at a depth of 60-90 cm in many of the boreholes.

Radiation profiles in the boreholes were determined by measuring gamma radiation levels at 15-30 cm intervals between the surface and the hole bottom. A collimated gamma scintillation detector and portable scaler were used for these measurements.

A calibration curve for converting direct radiation levels in the boreholes into thorium concentrations in soil was generated by plotting the gamma radiation level versus the thorium concentration in selected soil samples collected for this purpose.

## Soil Sampling

Soil samples (approximately 1 kg each) were collected from various depths in approximately 15% of the boreholes. Subsurface samples were obtained by

scraping soil from the side of the boreholes with a specially constructed sampler from which residual soil was cleaned between samples. Surface samples (0-15 cm) were collected using a garden trowel.

## Sediment Sampling

Sediment samples were collected at 100 m intervals along Kress Creek and the DuPage River. Samples were obtained with a split spoon sampler which was driven into the creek or river bed to a depth of at least 30 cm. Each core was then divided into 10 cm sections. Sampling locations are identified in Figure 12.

## Water Sampling

Six well water samples of approximately 3.5 liters each were obtained from local residences.

## Baseline and Background Measurements

Nine surface soil samples were collected at locations 1-7 km from Kress Creek; direct radiation levels were measured at these locations. Figure 13 indicates the locations of baseline samples and background measurements.

## Equipment and Analytical Procedures

Appendix C contains a list of the major equipment and instrumentation used for this survey. Analytical procedures are described in Appendix D.

## RESULTS

## Background Radiation and Baseline Concentrations

Background radiation levels and baseline radionuclide concentrations are presented in Table 1.

Background exposure rates in the West Chicago, Illinois, area ranged from 6-11 μR/h at 1 m (8.6 μR/h average) and from 7-12 μR/h at the surface (9.6 μR/h average).

Baseline radionuclide concentrations in soil were: Th-232, 0.53-1.12 pCi/g (picocuries per gram); Th-228, 0.50-1.12 pCi/g; total thorium, 1.03-2.10 pCi/g; Ra-226, 0.68-1.38 pCi/g; and U-238, 0.15-1.10 pCi/g. These concentrations are typical of those normally encountered in soil.

## Direct Radiation Levels

### Exposure Rates

Exposure rates measured systematically along the banks of Kress Creek and the DuPage River are presented in Tables 2 and 3.

Exposure rates 1 m above the surface at 1 m from the edge of the creek ranged from 8 to 96 μR/h averaging 28 μR/h. At 5 m from the edge, the exposure rates ranged from 7 to 72 μR/h (25 μR/h average); at 10 m, 8 to 120 μR/h (21 μR/h average); and, at 25 m, 8 to 32 μR/h (14 μR/h average).

Exposure rates along the banks of the DuPage River, upstream of its juncture with Kress Creek were: 10 to 19 μR/h (14 μR/h average) at 1 m from the edge of the river; 9 to 22 μR/h (15 μR/h average) at 5 m; 10 to 17 μR/h (13 μR/h average) at 10 m; and 10-14 μR/h (12 μR/h average) at 25 m. Downstream of the juncture with Kress Creek, exposure rates along the banks of the DuPage River were significantly higher. At 1 m from the river's edge exposure rates 1 m above the surface ranged from 14 to 104 μR/h (36 μR/h average). Exposure rates ranged from 11 to 64 μR/h (31 μR/h average) at 5 m; from 11 to 30 μR/h (18 μR/h average) at 10 m; and from 11 to 64 μR/h (20 μR/h average) at 25 m.

Exposure rates measured systematically at surface contact along the banks of the creek and river were generally about 20% higher than the levels measured at 1 m above the ground.

At 1, 5, 10, and 25 m from the edge of Kress Creek these levels ranged from 7-172 μR/h (36 μR/h average); 8-80 μR/h (27 μR/h average); 8-250 μR/h (24 μR/h average); and 8-38 μR/h (14 μR/h average), respectively. Along the DuPage River upstream of Kress Creek, the surface exposure rates were 10-22 μR/h (16 μR/h average) at 1 m from the river edge; 9-22 μR/h (16 μR/h average) at 5 m; 10-17 μR/h (14 μR/h average) at 10 m; and 11-16 μR/h (13 μR/h average) at 25 m. Downstream of the confluence with Kress Creek, the surface exposure rates along the banks of the DuPage River were 16-136 μR/h (45 μR/h average) at 1 m from the river edge; 13-88 μR/h (37 μR/h average) at 5 m; 11-32 μR/h (19 μR/h average) at 10 m; and 13-68 μR/h (21 μR/h average) at 25 m.

Several generalizations can be made regarding the systematic exposure rate measurements. Overall, exposure rates decrease with increasing distance from the edge of the creek, averaging 4 times background at the creek edge and decreasing to approximately 1.5 times background at 25 m. Although a similar decrease in exposure rate might be expected with increasing downstream distance, the same general levels of direct radiation are maintained throughout the length of the creek. One exception is that portion of the creek located 800 m to 1150 m downstream, north of Wilson Road. Here the exposure rates are somewhat below average, possibly due to the decreased tendency of the creek to overflow its banks in this region. Along the banks of the DuPage River upstream of its juncture with Kress Creek, the overall radiation levels are slightly above background. Downstream of Kress Creek, the exposure rates are substantially higher with average values exceeding those along Kress Creek itself. The highest exposure rates are found on the western bank of the river. Two possible explanations for this are that Kress Creek merges with the west side of the river and that the western bank is low-lying and more susceptable to flooding.

Beta-Gamma Surface Dose Rates

The systematically measured surface dose rates (μrad/h) typically ranged from 1-2 times the measured surface exposure rates (μR/h). Differences between the open- and closed-shield measurements averaged 26% indicating a small contribution from beta and low-energy photon radiations. Because of the

close relative agreement between the surface dose rates and surface exposure rates, the dose rate values have not been individually included in this report.

Walkover Surface Scan

The walkover surface scan, in addition to providing more detail, confirmed the general patterns identified by the systematic measurements. Numerous isolated regions were located in which the radiation levels were substantially elevated above those in adjacent areas. Exposure rates at several of these locations (also corresponding to the biased borehole locations) are presented in Table 4. These ranged up to 820 µR/h at the surface and 210 µR/h at 1 m above the surface. This highest level was noted 15 m east of the creek bank and 197 m downstream. Direct radiation levels at these isolated areas were generally higher upstream (closer to the sewer outfall) even though the overall radiation levels were reasonably constant along the length of the creek. Most of these locations were within 1-2 m of the edge of the creek and could be attributed to deposition during flooding. There were some areas of elevated exposure rates where the distance from the creek and/or the bank elevations would have precluded such deposition. One such area is on the east bank between 50 and 100 m downstream. In this example, elevated exposure rates were found near the end of a driveway, approximately 30 m from the creek and up a relatively steep incline.

Although the portion of the creek upstream of 0 m and downstream of the outfall could not be included in the survey, certain tentative assumptions can be drawn. Typical exposure rates along these banks are likely to be in the 20-50 µR/h range, slightly lower than earlier reports indicated. Since the banks are relatively low and the area prone to flooding, there may be more isolated areas of elevated direct radiation levels and these areas may be distributed further from the creek than was noted downstream.

Along the DuPage River elevated direct radiation levels on the west bank likely continue to at least 0.5 km downstream of the juncture with Kress Creek with a slight rise in the levels on the east bank possible. Beyond that

point, the west bank becomes steeper and less subject to flooding so that elevated radiation levels would be expected to be limited to the river edge.

Radionuclide Concentrations in Soil

A review of the analyses for 70 soil samples indicated that thorium is the radioactive material of concern at this site. Lower levels of Ra-226 and U-238 are present, at approximately 2.5% and 5% of the total thorium (Th-232 and Th-228) concentration respectively. Thorium-232 and thorium-228 were nearly always in secular equilibrium.

Total thorium concentrations determined for the systematic boreholes along Kress Creek and the DuPage River are presented in Tables 5 and 6, respectively. Total thorium concentrations for the biased boreholes are presented in Table 7.

Thorium concentrations in soil follow the same general pattern as the direct radiation levels - decreasing with distance from the edge of the creek. At 1 m from the edge, average concentrations at the various depths were: 26.1 pCi/g, surface; 40.2 pCi/g, 15 cm; 38.9 pCi/g, 30 cm; 28.9 pCi/g, 60 cm; and, 18.7 pCi/g, between 60 and 90 cm. These average values decrease by approximately 50% at 5 m from the edge of the creek, remain unchanged at 10 m, and at 25 m decrease to approximately 17% of the original concentration. At 25 m the average concentrations were approximately 3 times the baseline levels; however, the true averages may be slightly lower since the computer-generated curve used to calculate the thorium concentrations slightly overestimates concentrations near baseline levels.

Along the DuPage River, upstream of Kress Creek, the average thorium levels at 1 m from the river edge were: 3.45 pCi/g, surface; 4.86 pCi/g, 15 cm; 7.95 pCi/g, 30 cm; 5.09 pCi/g, 60 cm; and, 3.08 pCi/g, from 60-90 cm. These values showed a gradual decrease with distance from the edge of the river. At 25 m the thorium concentrations were only slightly above the baseline levels. Downstream of Kress Creek, the average concentrations at 1 m from the river edge were: 12.5 pCi/g, surface; 18.1 pCi/g, 15 cm; 30.8 pCi/g, 30 cm; 15.8 pCi/g, 60 cm; and, 11.3 pCi/g from 60-90 cm.

As was true of the direct radiation levels, the thorium concentrations in soil did not indicate a significant overall decrease with increasing downstream distance along those parts of the creek and river included in the survey. Concentrations on the west bank of the DuPage River were only slightly lower than those on the creek banks nearest the Kerr-McGee outfall. The highest level of total thorium measured in a sample (555 pCi/g) was 60 cm deep in a systematic borehole 1750 m downstream and 1 m from the west side of the creek. Other high levels were in the three biased boreholes collected closest to the outfall: 197 m downstream, 15 m from the east edge of the creek - 489 pCi/g; 25 m downstream, 1 m from the east edge of the creek - 432 pCi/g; and, 205 m downstream, 12 m from the east edge of the creek - 417 pCi/g. While the overall concentrations decrease very little along the length of the creek, the highest levels are at isolated upstream locations nearest the outfall.

The average concentrations along Kress Creek and the DuPage River do not reflect the localized distribution of the contamination however. In order to provide such information, the thorium concentrations in soil from Tables 5, 6, and 7 were evaluated in combination with the results of the walkover surface scan. Estimates were made of the locations in which thorium concentrations in soil ranged from 10-20 pCi/g, 20-50 pCi/g, and >50 pCi/g. These estimates are presented in Figures 14, 15, 16, and 17. The figures indicate maximum concentrations at a given location, regardless of the depth of the contamination. Except for a few areas - most notably around Gunness Lake - the contamination is predominantly on one bank or the other. Frequently, this bank is on the inside of a curve or bend in the creek and prone to flooding. As a result, along much of the creek the thorium concentrations on one bank will be well below 10 pCi/g even though the average value may be higher.

Maximum thorium concentrations were typically 15-30 cm deep along the banks of both Kress Creek and the DuPage River. The greatest depth at which a maximum thorium concentration was encountered in a borehole was at 110 cm in the systematic borehole 50 m downstream and 10 m from the east edge of the creek (226 pCi/g). This was a unique situation and not easily attributed to deposition brought about by a periodic flooding of the creek. The depth of the material, together with the steepness of the bank and the pattern of the

surface exposure rates observed in the walkover scan, suggest that contaminated fill may have been used during landscaping of the property.

The maximum depths to which thorium concentrations of 10-20 pCi/g, 20-50 pCi/g, and >50 pCi/g are present, average between 30-60 cm. Conservative estimates of these depths are 60, 55, and 50 cm respectively. There is also a general tendency for the depth of the contamination to decrease with distance from the edge of the creek or river.

## Radionuclide Concentrations in Sediment

Radionuclide concentrations in sediment samples along Kress Creek and the DuPage River are presented in Tables 8 and 9, respectively. In almost all cases, secular equilibrium was observed between Th-232 and Th-228. Along Kress Creek the total thorium concentrations ranged from <0.34 to 131 pCi/g. Contrary to what might be expected, there was no overall decrease in the thorium concentrations with increasing downstream distance. Instead, the thorium levels appeared to fluctuate randomly; the highest concentration was observed at the 1850 m downstream distance while the sample immediately downstream (1950 m) had one of the lowest concentrations. There are several factors which may explain the fluctuations. To some degree, the small samples obtained with the split spoon sampler may not have been representative of the sediment at any given location. More likely, the observations reflect differential deposition of thorium resulting from changing conditions of the stream bed and changes in the direction and rate of stream flow, i.e. placer deposition. Both the fluctuations in thorium levels and the general range of these levels are consistent with the results of the initial survey of Kress Creek performed by Oak Ridge Associated Universities.[4]

Along the DuPage River, as expected, the downstream sediments had considerably higher thorium concentrations (up to 27.2 pCi/g) than the samples collected upstream of the juncture with Kress Creek (up to 2.24 pCi/g).

Thorium concentrations decreased with depth. In almost all cases, the concentrations reached what could be considered baseline levels at a depth of 20-30 cm; however, in the sediment collected at 0 m (the sampling location

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closest to the outfall), they remained essentially constant down to 40 cm (at approximately 50 pCi/g).

These findings suggest that thorium levels in the creek sediment between 0 m and the storm sewer outfall will exceed 50 pCi/g and that the depth of the contamination will be greater than that observed along the rest of the creek.

The uniform nature of the DuPage River indicates that the progressive decrease in thorium concentration observed in the river sediment between Kress Creek and 200 m downstream would likely continue.

Radionuclide Concentrations in Water Samples

Gross alpha and beta concentrations in the residential well water samples are presented in Table 10.

The gross alpha concentrations ranged from <1.33 to 1.48 pCi/l, and gross beta concentrations ranged from <2.26 to 4.98 pCi/l. Because of these low levels, no further isotopic analyses were necessary.

SUMMARY

At the request of the Nuclear Regulatory Commission, the ORAU Radiological Site Assessment Program conducted a radiological survey of portions of Kress Creek and the DuPage River in the West Chicago Area, Illinois. The survey findings indicated thorium contamination in soil and sediment along certain sections of the creek and river. Radionuclides of the uranium decay series, i.e. uranium-238 and radium-226, are also present, but in quantities so low in comparison with the thorium as to be inconsequential.

The contamination originated on property originally owned by Lindsay Light and Chemical Company and now owned by Kerr-McGee Corporation. Contaminated residues from two waste piles on the property were carried by precipitation-induced runoff into a nearby storm sewer which subsequently emptied into Kress Creek. From there it was transported down the remaining 2 km of Kress Creek and into the west branch of the DuPage River.

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The thorium contaminated residues were deposited along the streambed and banks, primarily at locations where the creek flow abruptly changed speed or direction. In many areas flooding deposited the material well beyond the immediate banks of the creek. In at least one area, elevated thorium levels, which appear to have resulted from the use of contaminated backfill, were observed. Overall contamination levels decreased slightly along the length of the creek and downstream along that portion of the DuPage River included in the survey. The contamination is primarily limited to the upper 60-90 cm of soil with the maximum levels located at depths of 15-30 cm. Low gross alpha and beta concentrations in the residential well water samples are consistent with the low solubility of the material. It is likely that the primary mode for the exposure of the local population is external gamma radiation. In a couple of cases, vegetable gardens located in moderately contaminated areas offer an additional, although probably not major, pathway for exposure.

The levels of direct radiation and radionuclide concentations in soil and sediment at many locations along Kress Creek and the DuPage River exceed target criteria proposed by the EPA and NRC for uncontrolled use by the general public. These criteria were developed to implement the philosophy of these agencies that unnecessary exposures to radiation should be reduced or eliminated to the extent practicable.
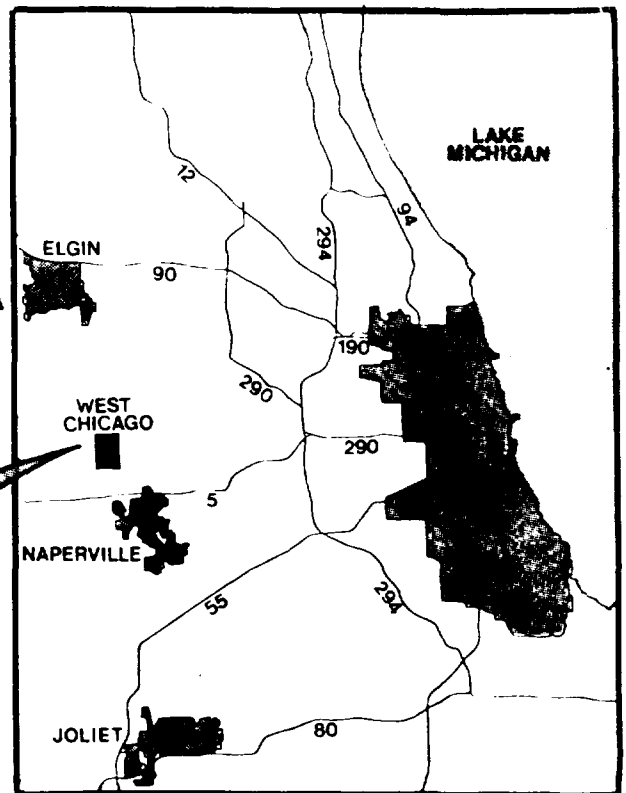
FIGURE 1. Map of Chicago, Illinois, and
Vicinity Indicating the Location of
Kress Creek.
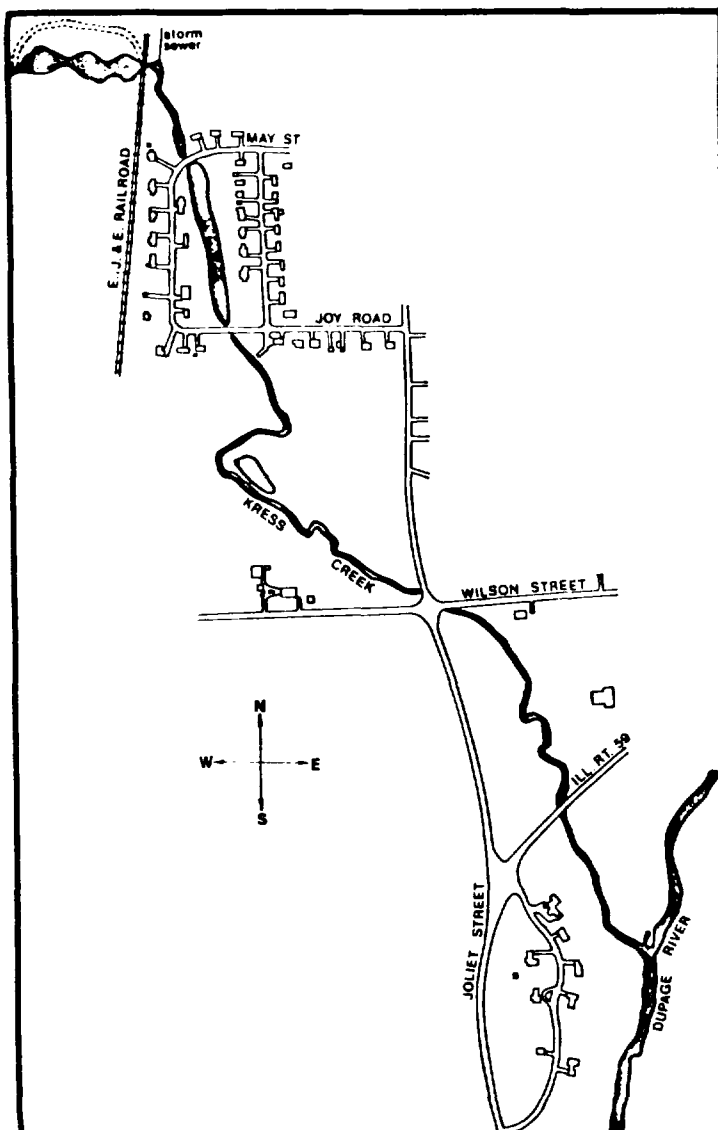


FIGURE 2. Portion of West Chicago,
Illinois, Indicating Sections of
Kress Creek and the DuPage River.

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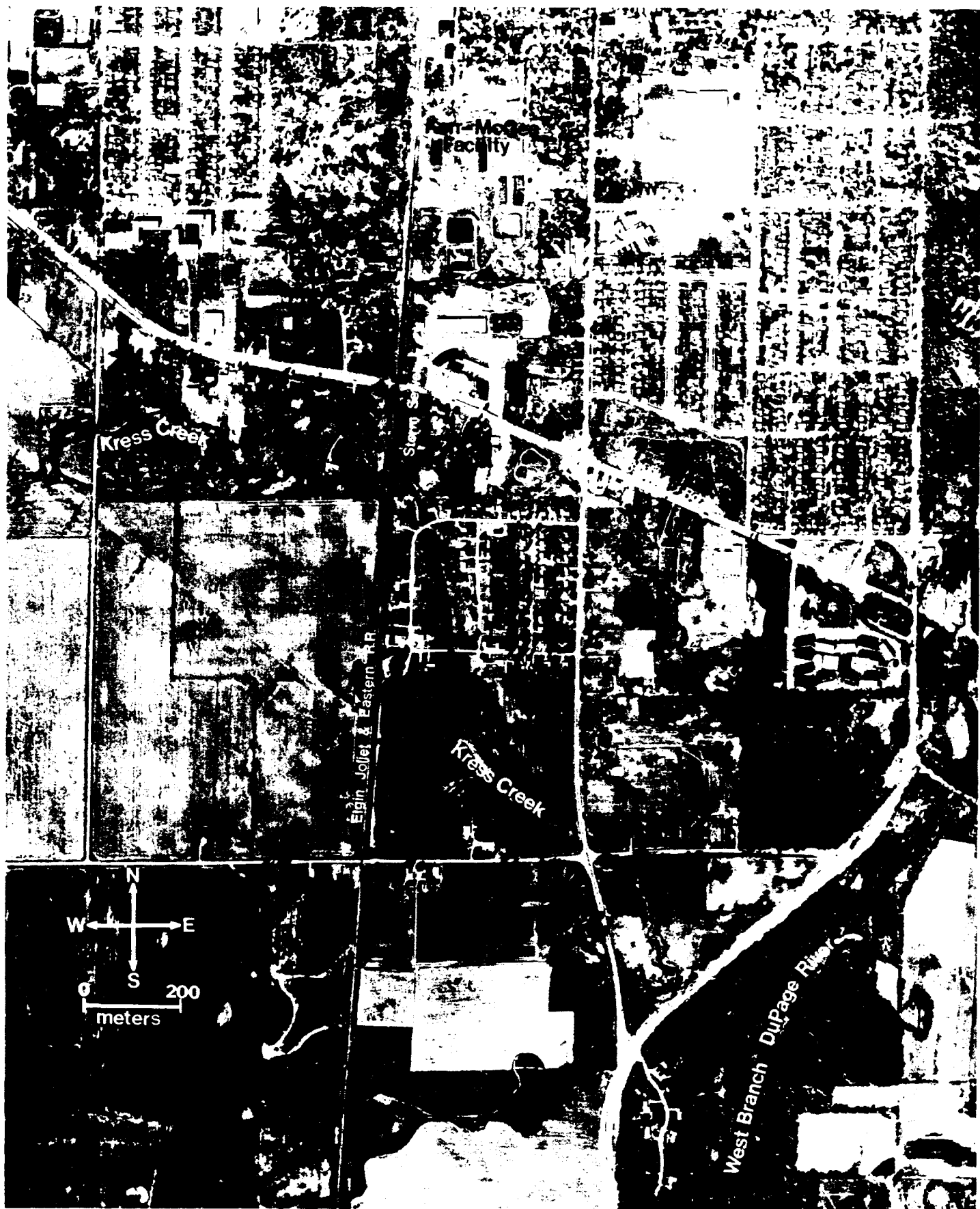
FIGURE 3. Aerial Photograph of West Chicago, Illinois, Indicating
Sections of Kress Creek and the Dupage River.
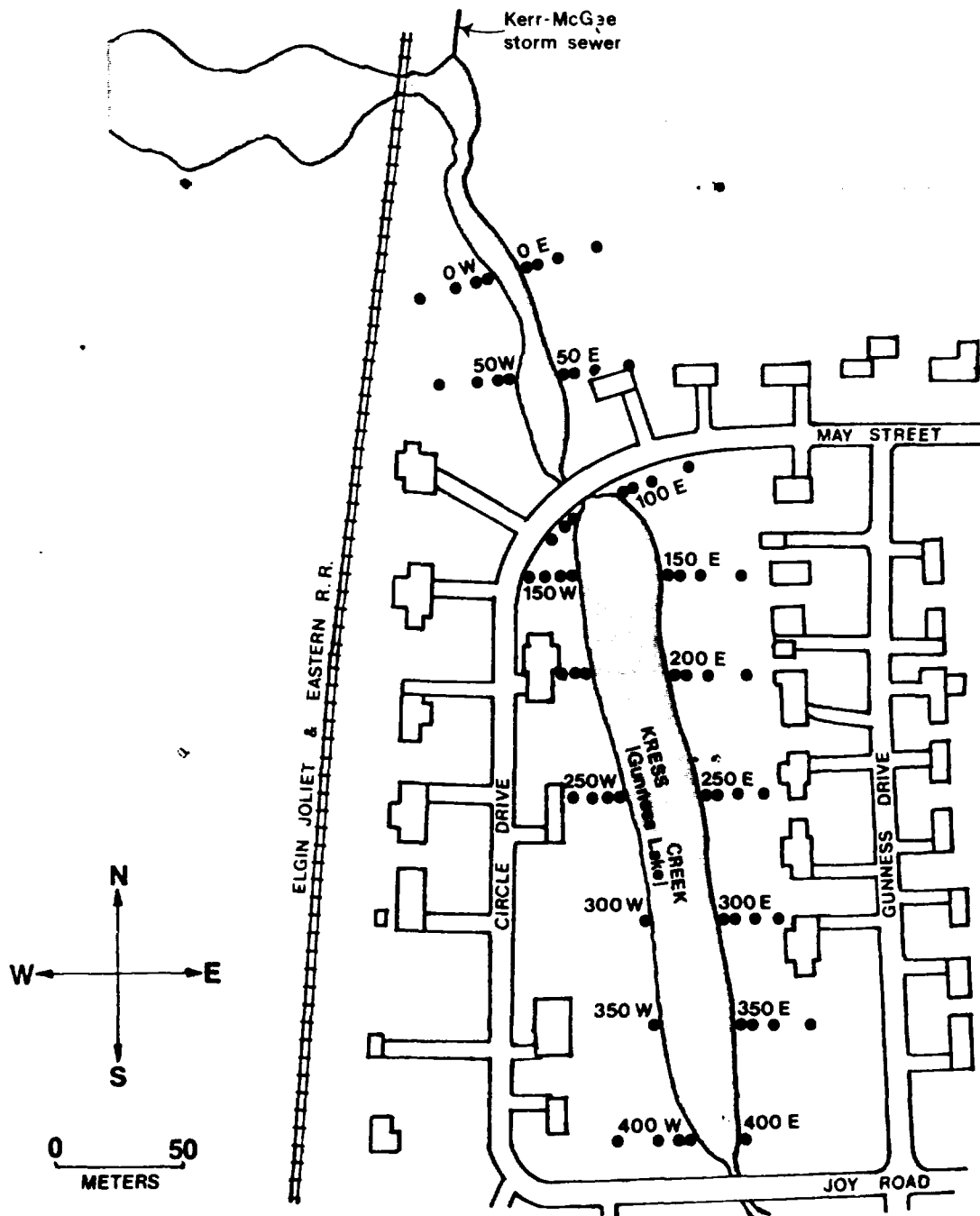
FIGURE 4. Map of Kress Creek Between the Storm Sewer Outfall and Joy Road Indicating Locations of the Systematic Direct Radiation Measurements.

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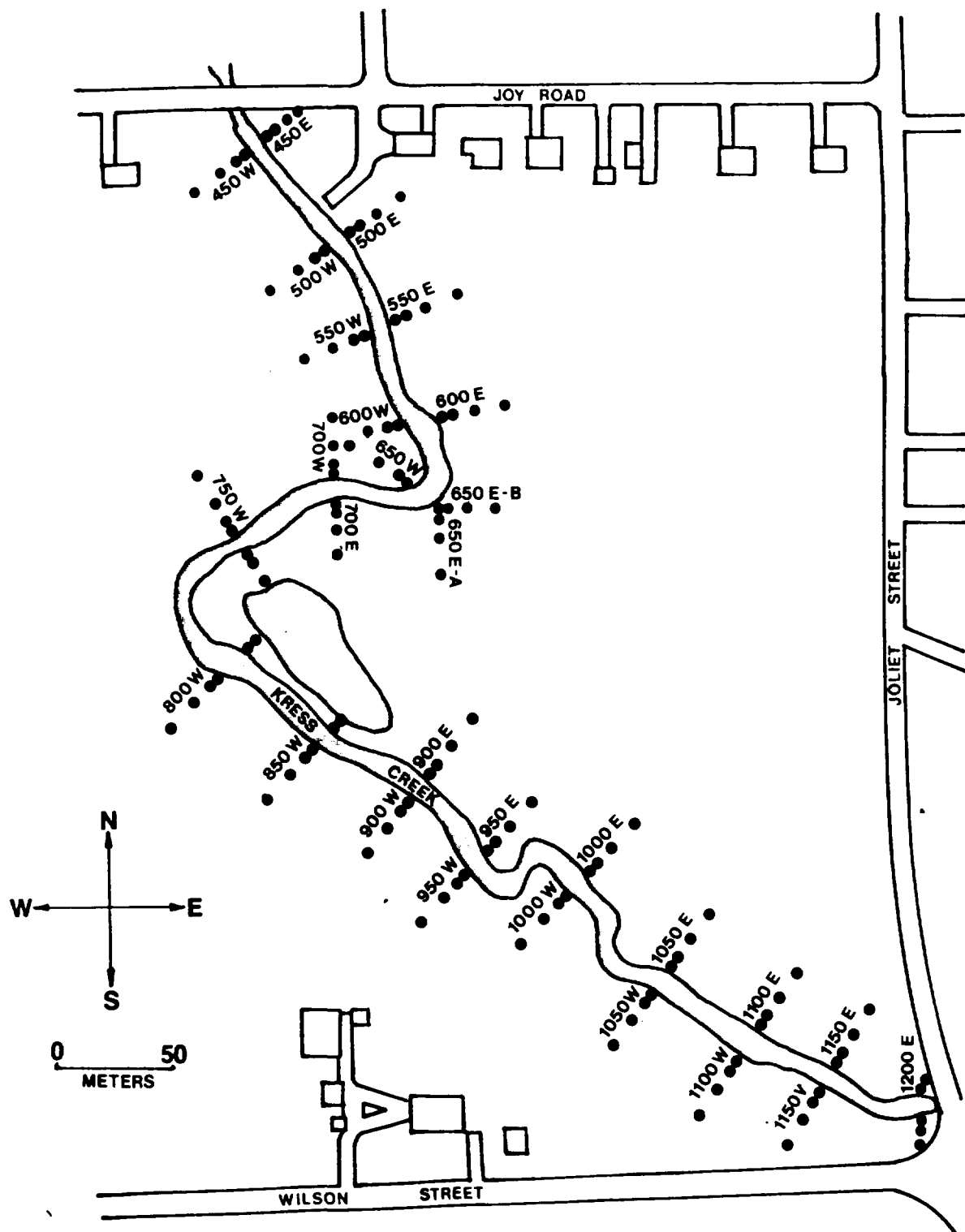
FIGURE 5. Map of Kress Creek Between Joy Road and Wilson Street Indicating
Locations of the Systematic Direct Radiation Measurements.

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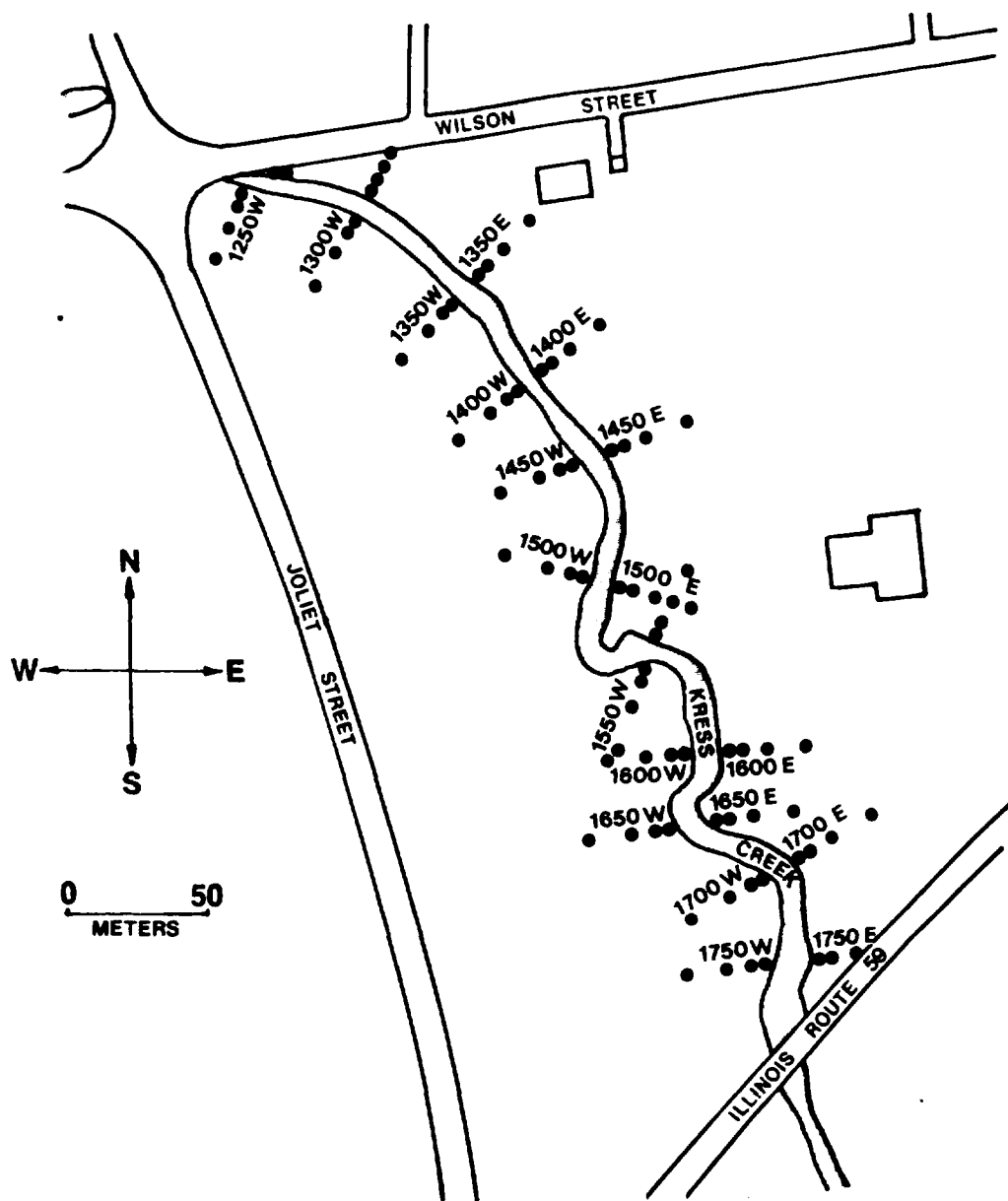
FIGURE 6. Map of Kress Creek Between Wilson Street and Illinois Route 59
Indicating Locations of the Systematic Direct Radiation
Measurements.
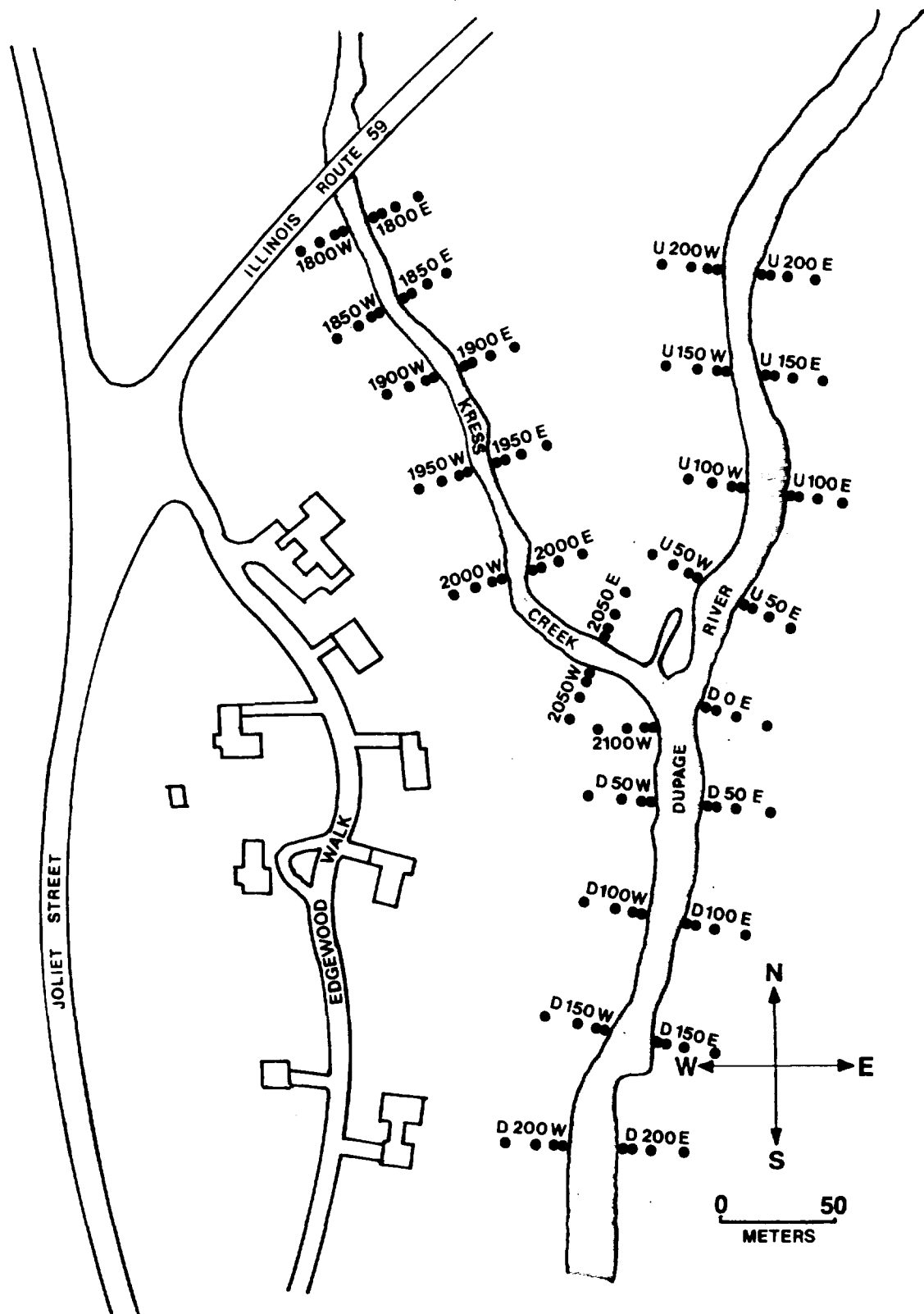
FIGURE 7. Map of Kress Creek Between Illinois Route 59 and the DuPage
River Indicating Locations of the Systematic Direct Radiation
Measurements.
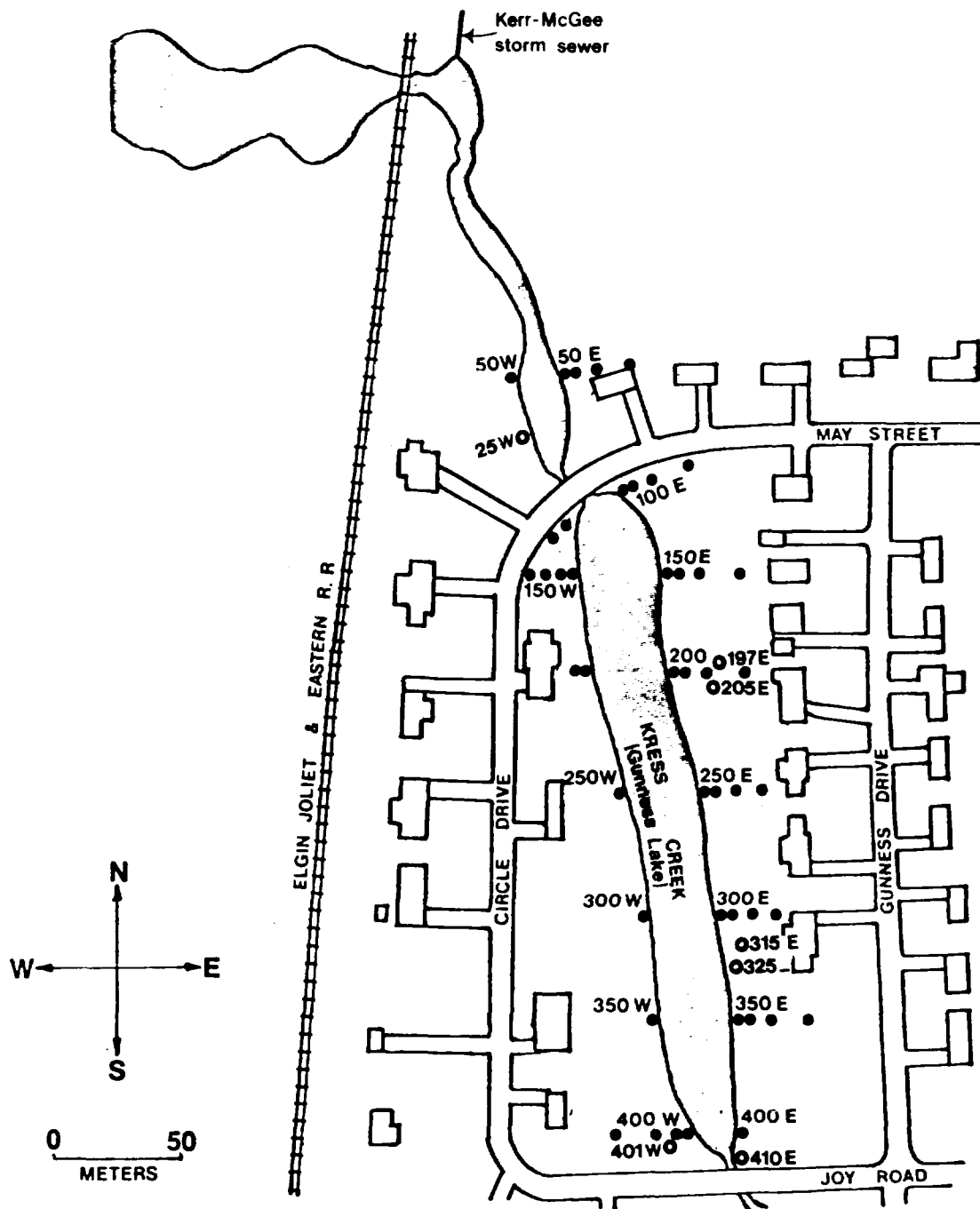
FIGURE 8.  Map of Kress Creek Between the Storm Sewer Outfall and
Joy Road Indicating Borehole Locations. (Systematic and
biased boreholes are indicated by closed and open circles
respectively.)

21
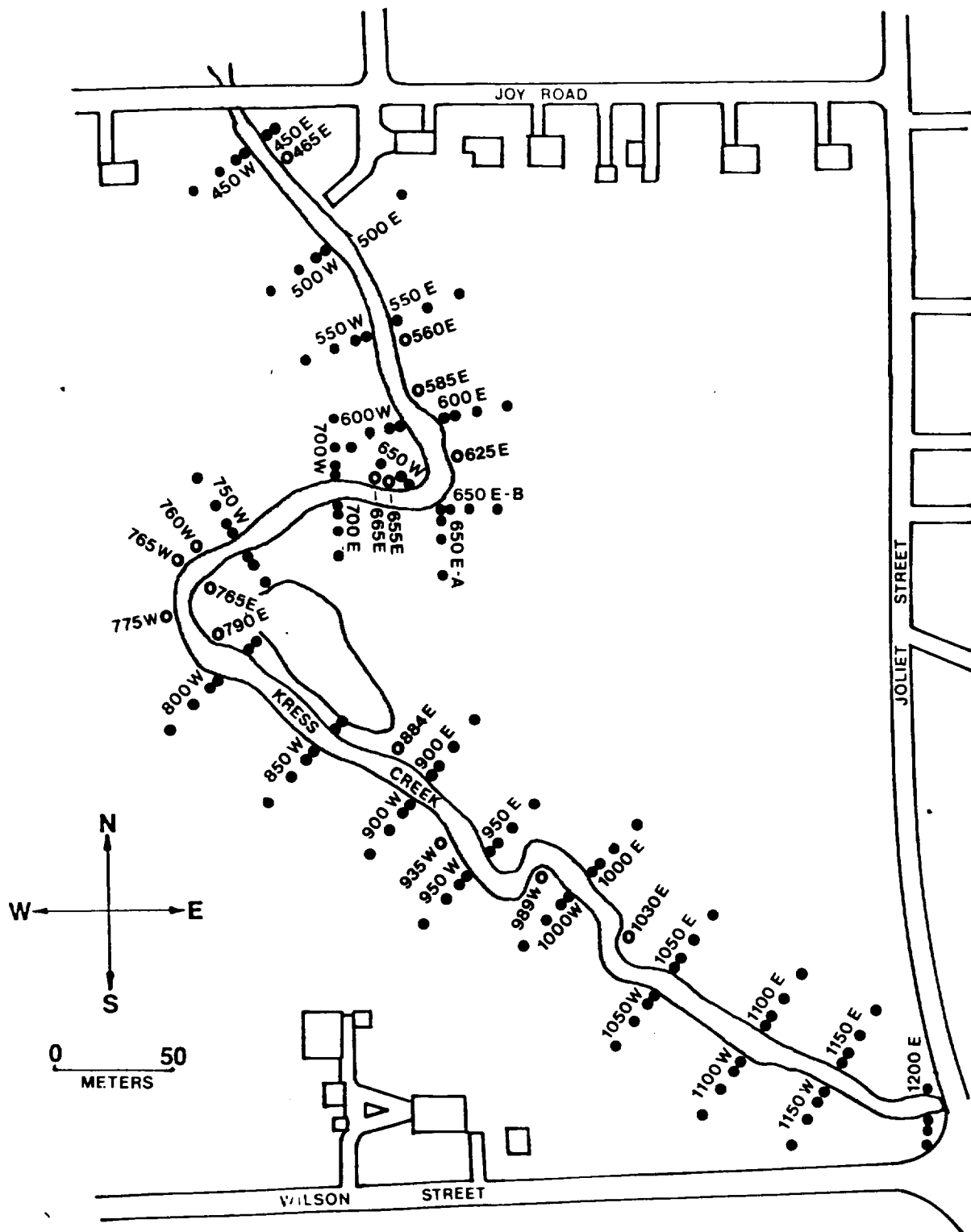
FIGURE 9. Map of Kress Creek Between Joy Road and Wilson Street Indicating Borehole Locations. (Systematic and biased boreholes are indicated by closed and open circles respectively.)

22
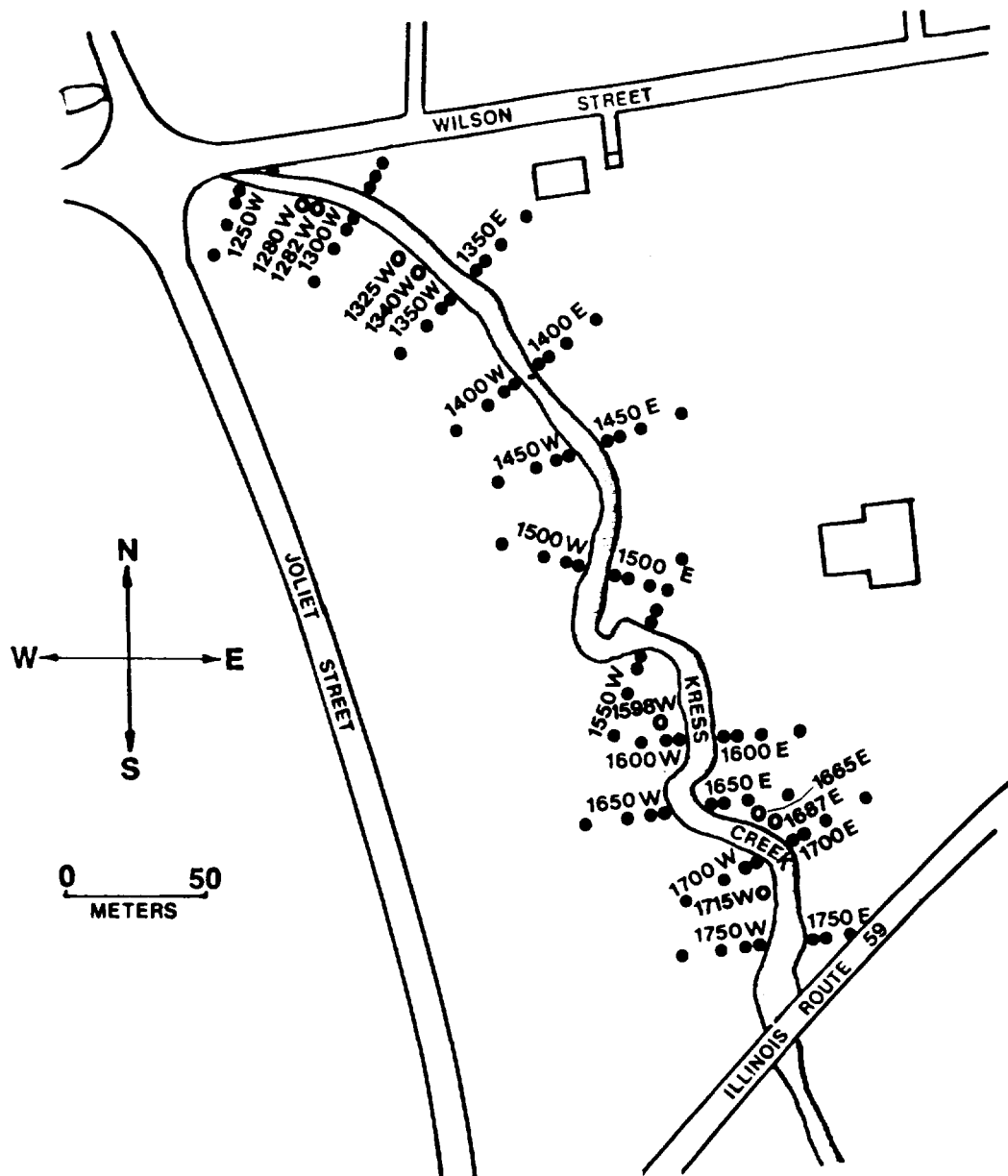
FIGURE 10. Map of Kress Creek Between Wilson Street and Illinois
Route 59 Indicating Borehole Locations. (Systematic and
biased boreholes are indicated by closed and open
circles respectively.)

23
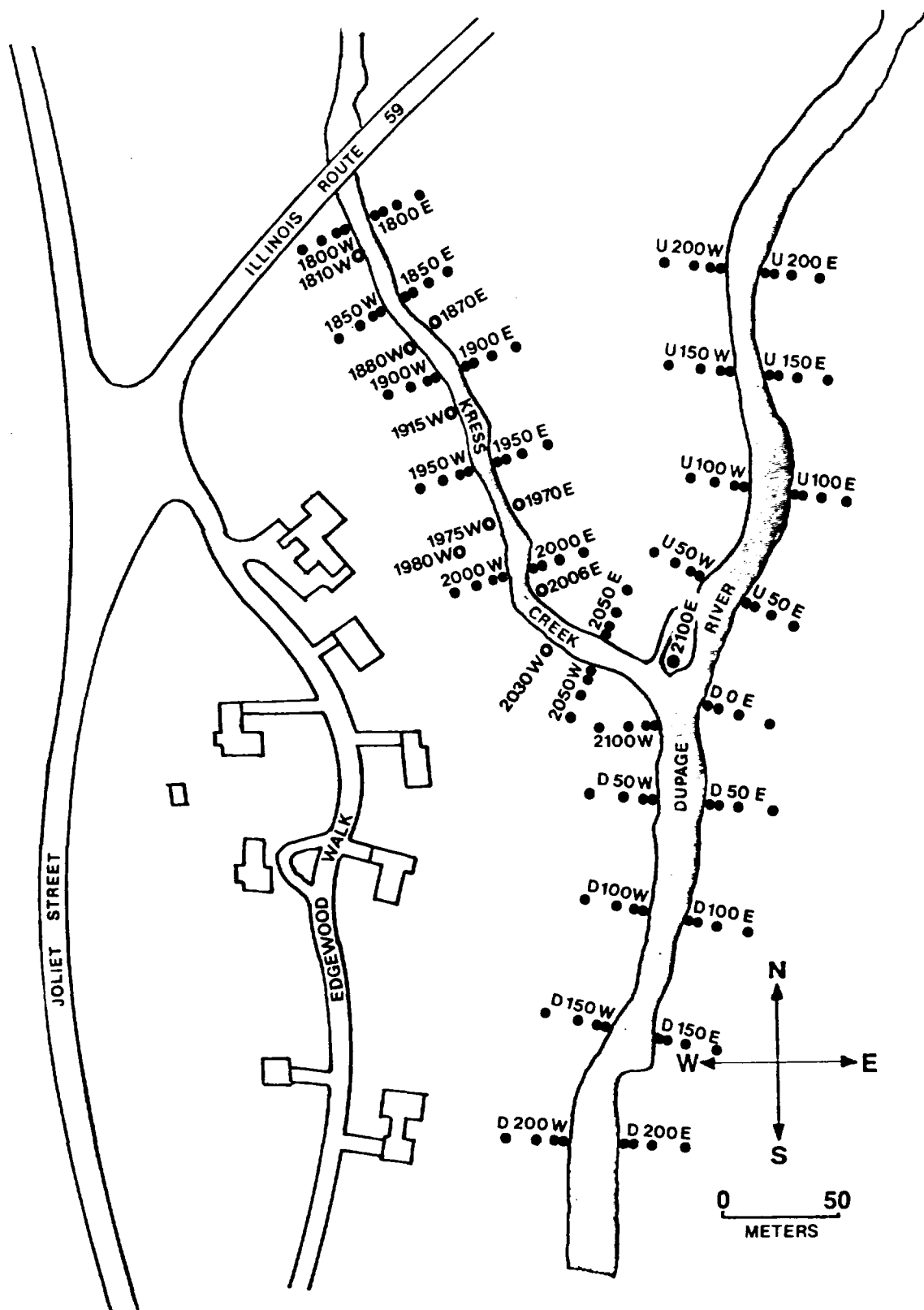
FIGURE 11.    Map of Kress Creek Between Illinois Route 59 and the DuPage
River Indicating Borehole Locations.  (Systematic and biased
boreholes are indicated by closed and open circles, respectively.)

24
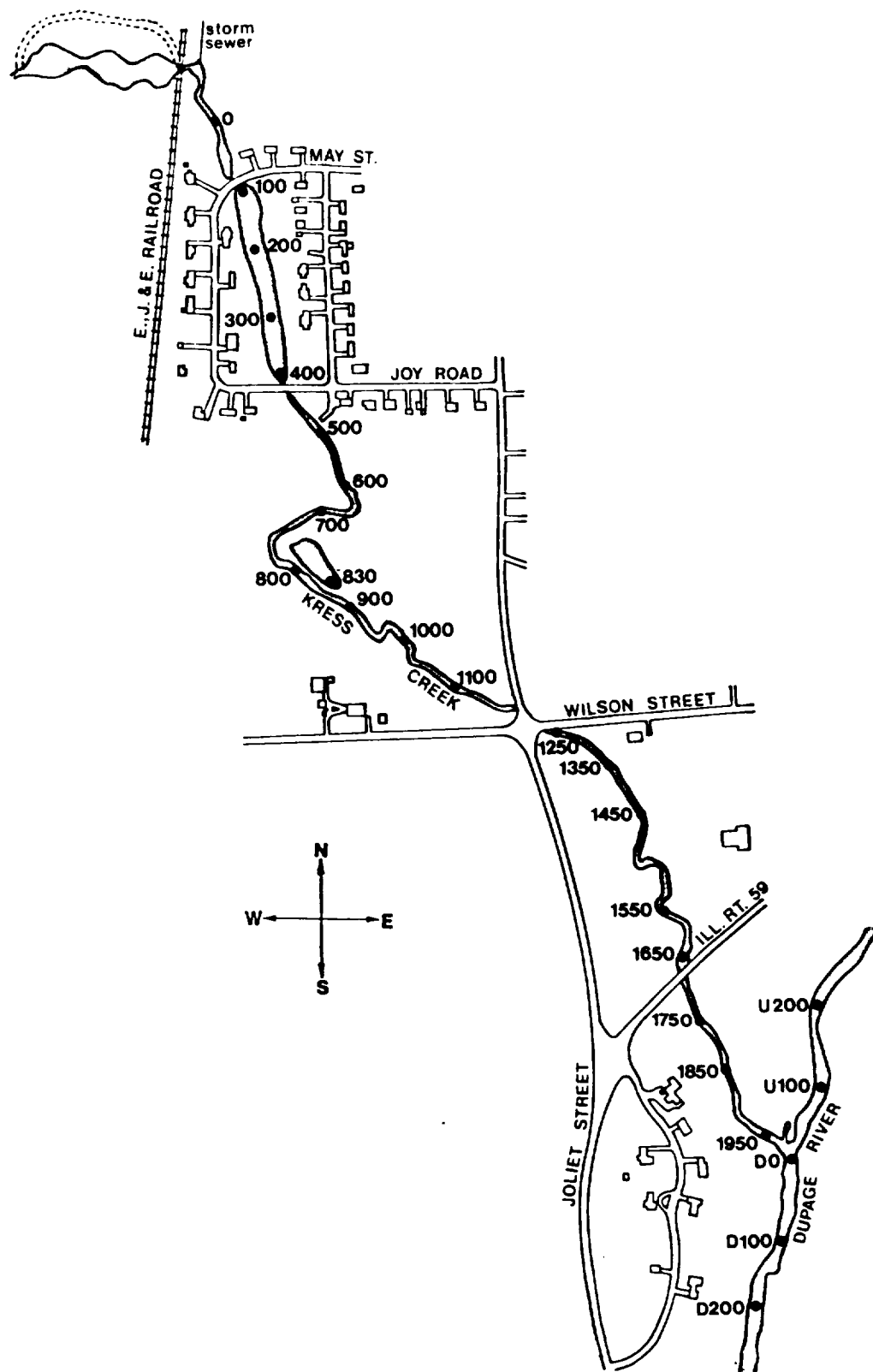
FIGURE 12. Map of Kress Creek Indicating Sediment Sampling
Locations.
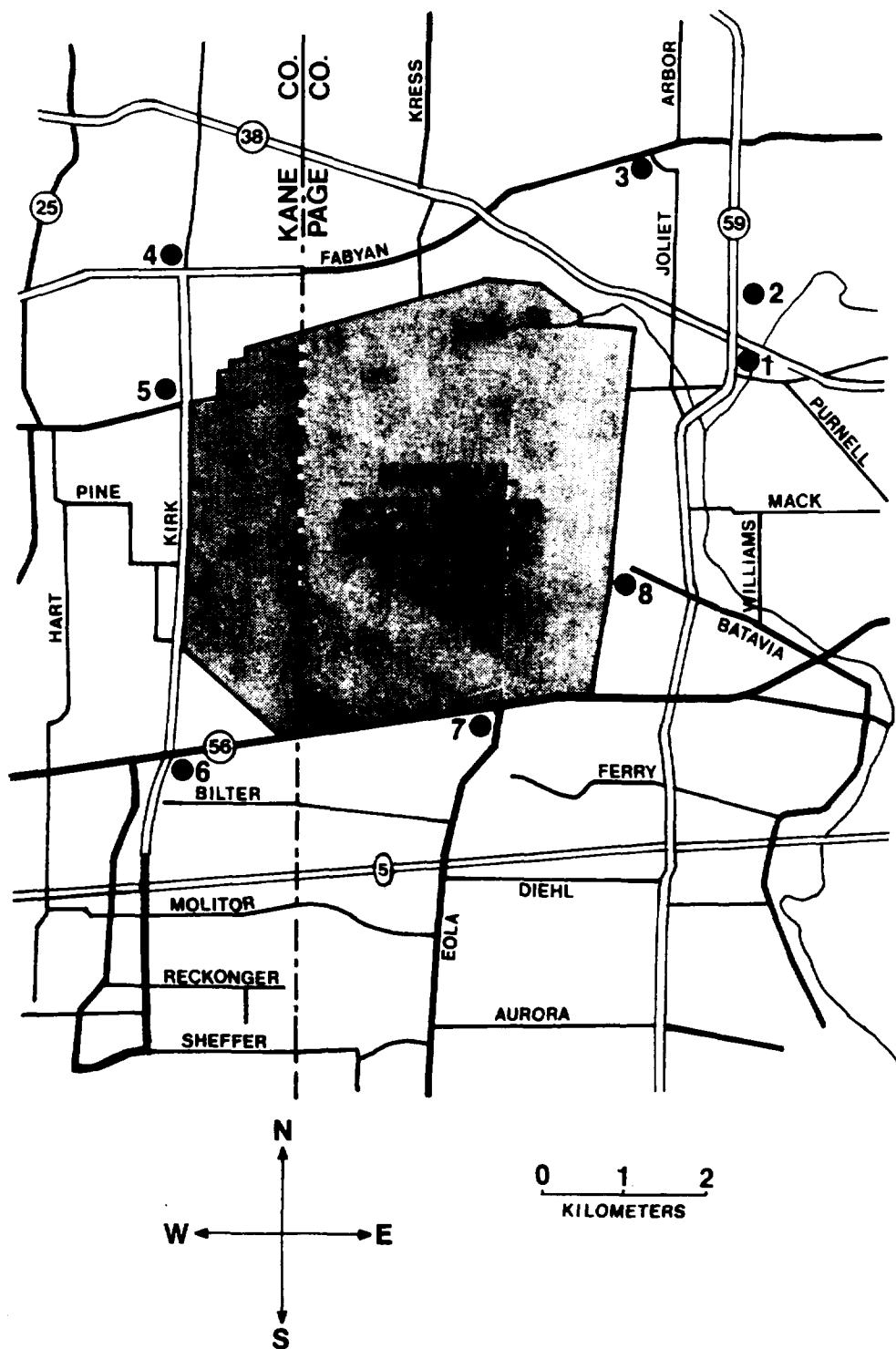
FIGURE 13. Map of West Chicago and Vicinity Indicating Locations of the Background Measurements and Baseline Samples.
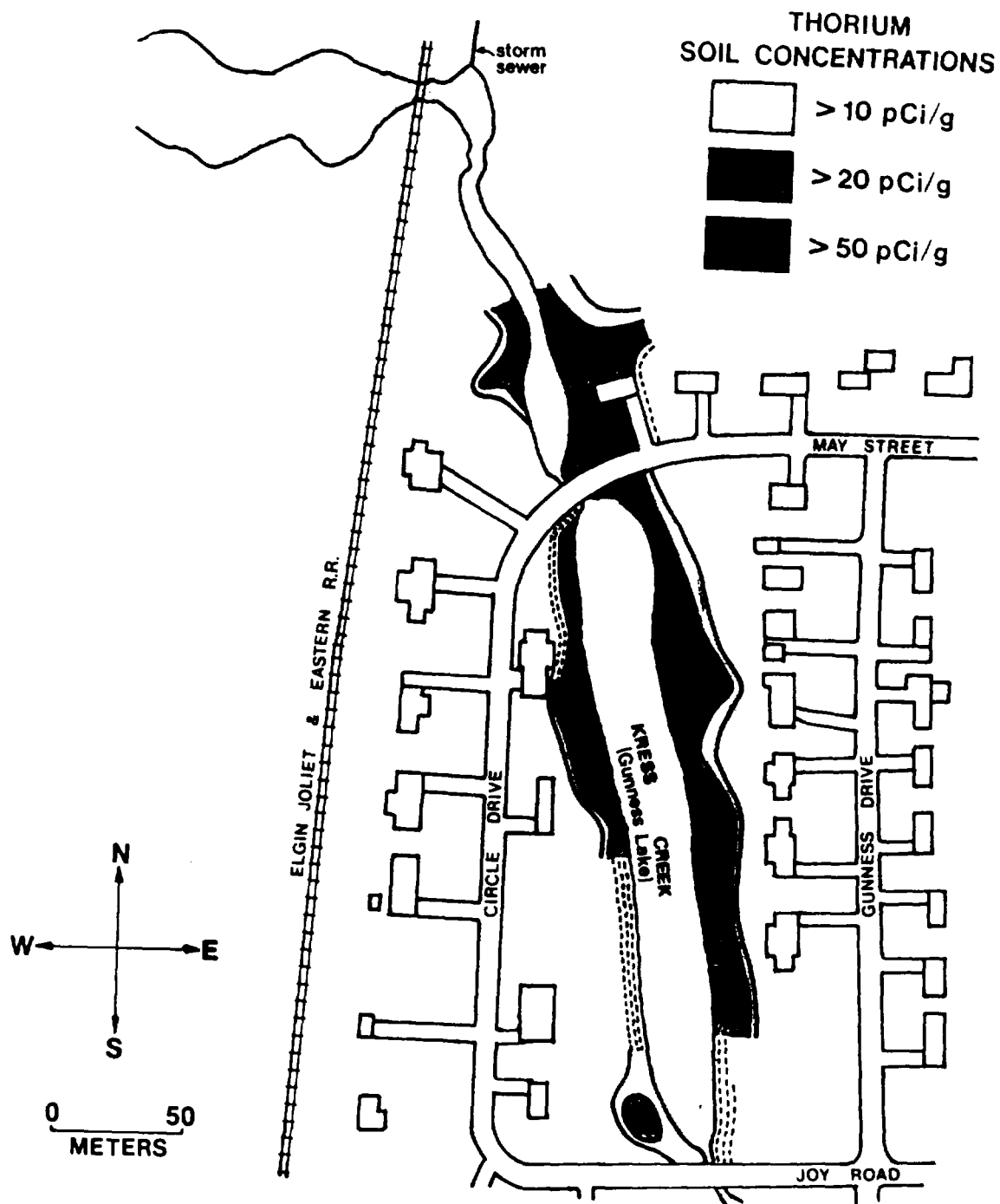
FIGURE 14. Map of Kress Creek Between the Storm Sewer Outfall and Joy Road Indicating Total Thorium Concentrations in Soil.
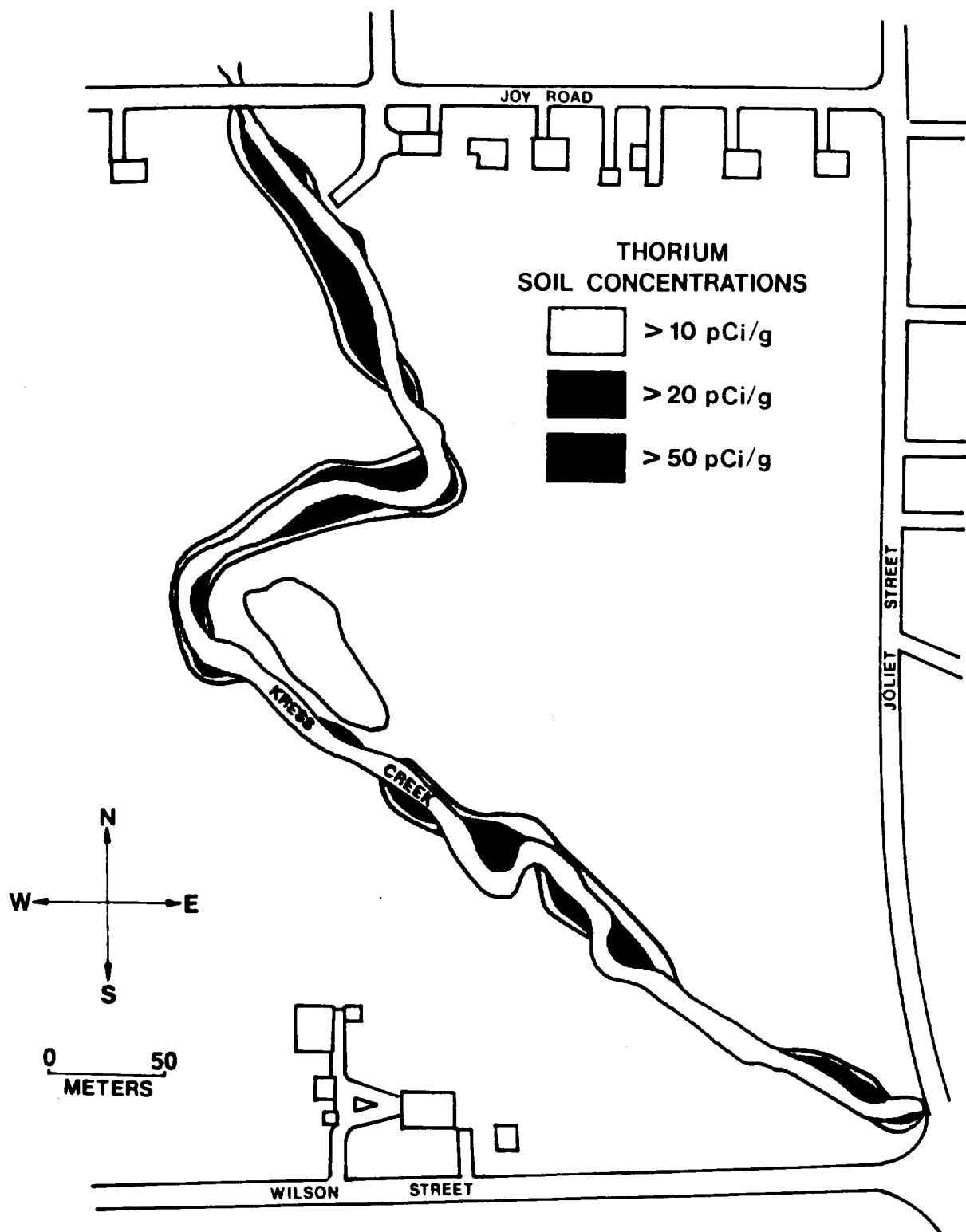
FIGURE 15.  Map of Kress Creek Between Joy Road and Wilson Street
Indicating Total Thorium Concentrations in Soil.
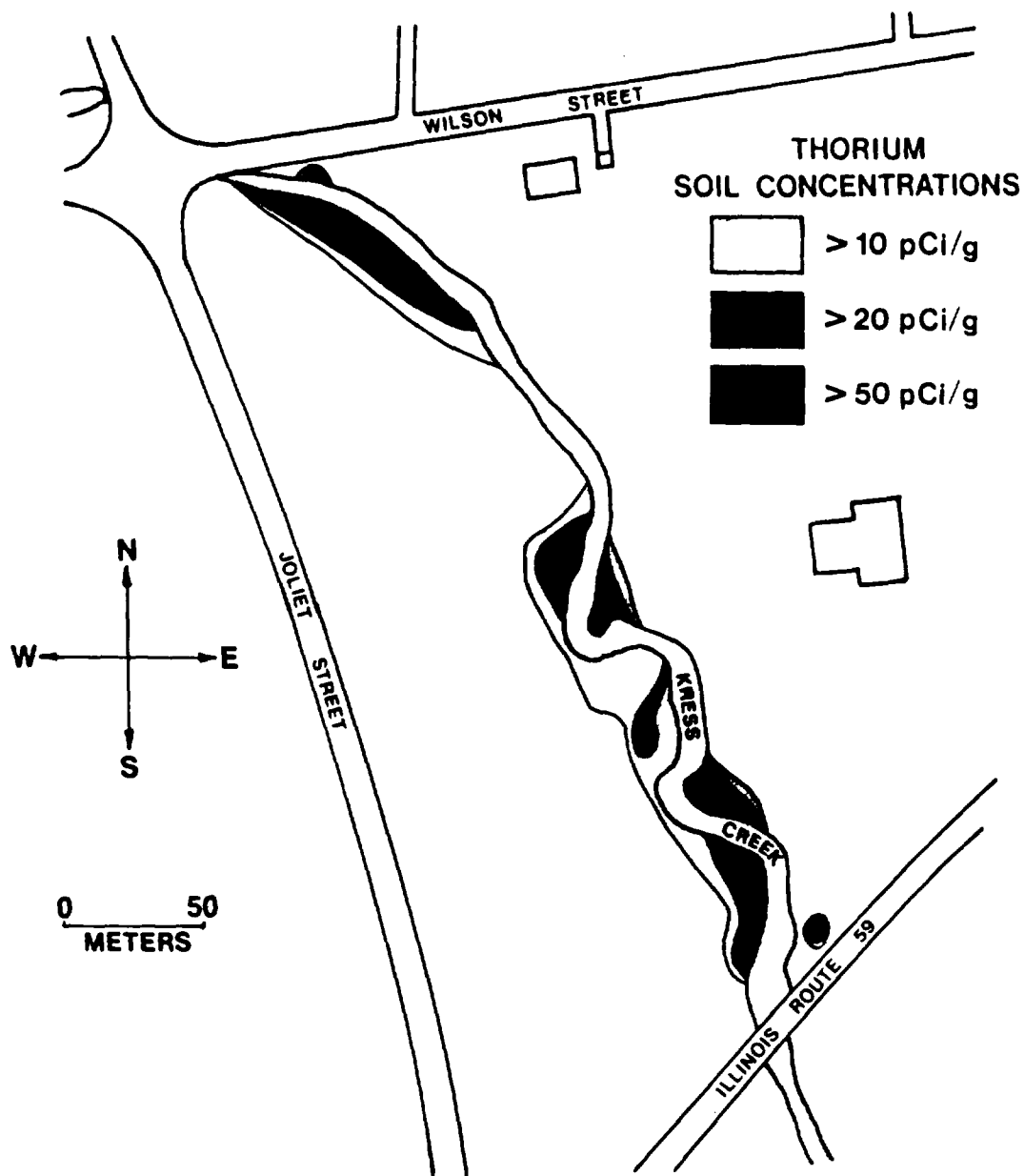
FIGURE 16. Map of Kress Creek Between Wilson Street and Illinois Route 59 Indicating Total Thorium Concentrations in Soil.

THORIUM
SOIL CONCENTRATIONS

> 10 pCi/g

> 20 pCi/g

> 50 pCi/g

ILLINOIS ROUTE 59

KRESS

CREEK

RIVER

DUPAGE

JOLIET STREET

N

W ← → E

S

0 _____ 50
METERS
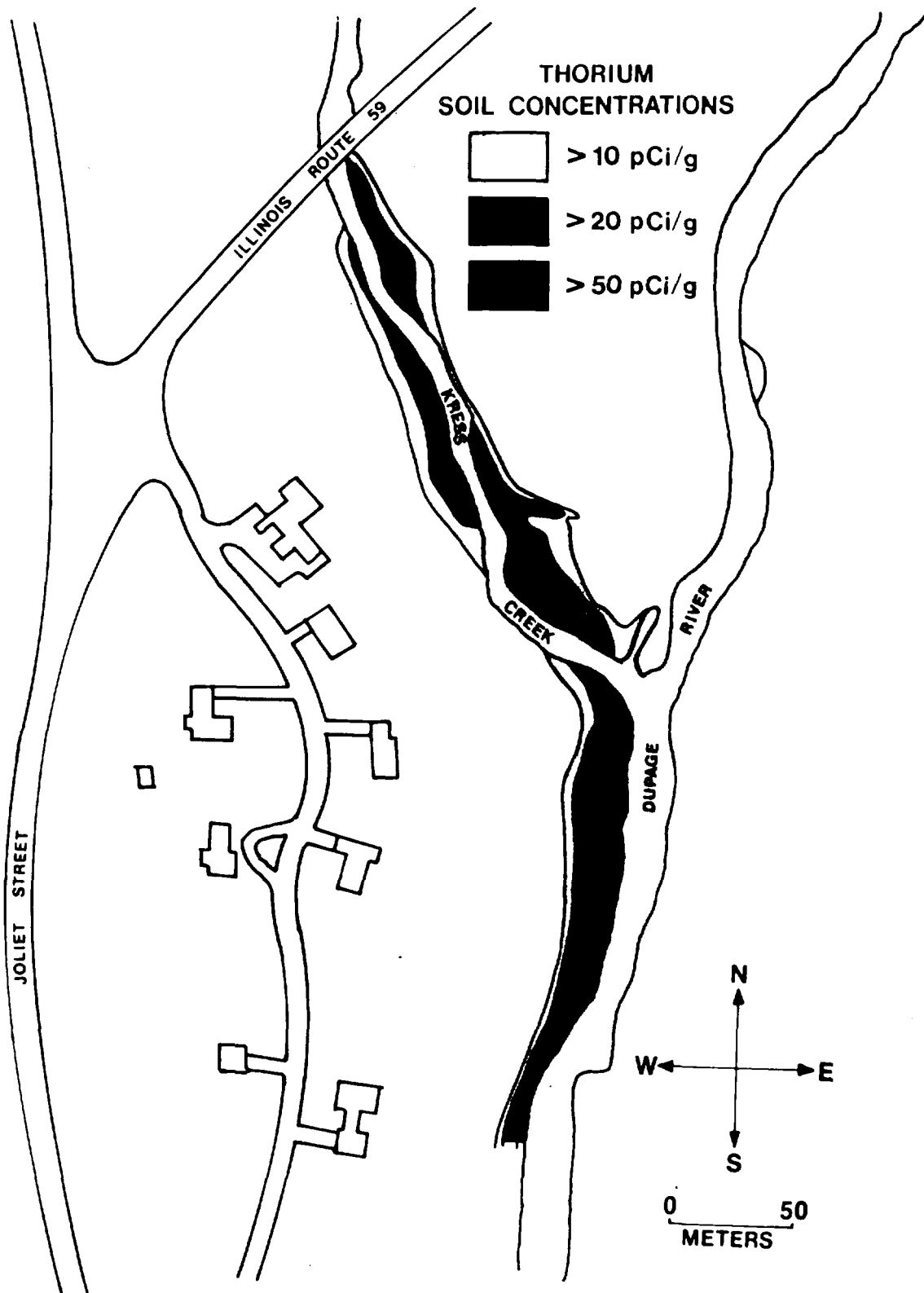
FIGURE 17.   Map of Kress Creek Between Illinois Route 59 and the DuPage
River Indicating Total Thorium Concentrations in Soil.

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TABLE 1

BACKGROUND DIRECT RADIATION LEVELS AND
RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL SAMPLES

| Location[a] | Exposure Rate ($\mu$R/h) | | Radionuclide Concentration (pCi/g) | | | | |
|---|---|---|---|---|---|---|---|
| | 1 m | Surface | Th-232 | Th-228 | Total Thorium (Th-232 & Th-228) | Ra-226 | U-238 |
| 1 | 6 | 7 | 0.59 ± 0.26[b] | 0.82 ± 0.24 | 1.41 | 0.73 ± 0.17 | 0.35 ± 0.74 |
| 2 | 9 | 10 | 0.65 ± 0.37 | 1.12 ± 0.28 | 1.77 | 1.18 ± 0.31 | 0.63 ± 1.54 |
| 3 | 8 | 10 | 0.61 ± 0.25 | 0.59 ± 0.17 | 1.20 | 0.80 ± 0.21 | 0.56 ± 0.54 |
| 4 | 8 | 9 | 0.92 ± 0.40 | 0.94 ± 0.38 | 1.86 | 1.35 ± 0.31 | 1.10 ± 0.89 |
| 5 | 11 | 12 | 0.85 ± 0.27 | 0.72 ± 0.19 | 1.57 | 0.82 ± 0.21 | 0.15 ± 0.28 |
| 6 | 11 | 11 | 0.75 ± 0.46 | 1.10 ± 0.36 | 1.85 | 1.38 ± 0.29 | 0.59 ± 1.22 |
| 7 | 7 | 8 | 0.53 ± 0.21 | 0.50 ± 0.21 | 1.03 | 0.68 ± 0.21 | 0.22 ± 0.52 |
| 8 | 9 | 10 | 1.12 ± 0.37 | 0.98 ± 0.33 | 2.10 | 1.12 ± 0.33 | 0.82 ± 0.52 |
| Range | 6-11 | 7-12 | 0.53 - 1.12 | 0.50 - 1.12 | 1.03 - 2.10 | 0.68 - 1.38 | 0.15 - 1.10 |
| Average | 8.6 | 9.6 | 0.75 | 0.85 | 1.60 | 1.01 | 0.57 |

[a] Refer to Figure 13.
[b] Errors are 2$\sigma$ based on counting statistics.

TABLE 2

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m)[a] | Measurement | Exposure Rate (μR/h) | | | | | | | |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 m | 12 | 16 | 19 | 19 | 24 | 22 | 17 | 11 |
| | Surface | 13 | 19 | 22 | 28 | 26 | 24 | 19 | 13 |
| 50 | 1 m | 13 | 13 | 26 | 26 | 30 | 26 | 22 | 22 |
| | Surface | 17 | 13 | 28 | 22 | 32 | 28 | 22 | 24 |
| 100 | 1 m | —[b] | 11 | 16 | 28 | 22 | 28 | 18 | 10 |
| | Surface | — | 11 | 12 | 28 | 38 | 24 | 17 | 11 |
| 150 | 1 m | 8 | 15 | 13 | 14 | 13 | 22 | 19 | 8 |
| | Surface | 10 | 16 | 13 | 16 | 11 | 24 | 22 | 8 |
| 200 | 1 m | — | 17 | 30 | 28 | 34 | 48 | 120 | 24 |
| | Surface | — | 16 | 34 | 32 | 44 | 44 | 250 | 24 |
| 250 | 1 m | 16 | 24 | 36 | 50 | 16 | 18 | 22 | 13 |
| | Surface | 17 | 26 | 50 | 100 | 17 | 17 | 22 | 14 |
| 300 | 1 m | — | — | 26 | 24 | 16 | 19 | 24 | 12 |
| | Surface | — | — | 26 | 30 | 17 | 19 | 24 | 13 |
| 350 | 1 m | — | — | — | 50 | 17 | 16 | 22 | 10 |
| | Surface | — | — | — | 56 | 18 | 30 | 22 | 11 |
| 400 | 1 m | 11 | 32 | 36 | 22 | 30 | 26 | 22 | 19 |
| | Surface | 11 | 40 | 44 | 22 | 48 | 28 | 22 | 19 |

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DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Measurement | Exposure Rate (μR/h) | | | | | | | |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
|---|---|---|---|---|---|---|---|---|---|
| 450 | 1 m | 10 | 11 | 13 | 34 | 20 | 11 | 9 | 8 |
| | Surface | 10 | 10 | 12 | 50 | 24 | 12 | 8 | 9 |
| 500 | 1 m | 10 | 16 | 52 | 88 | 16 | 13 | 10 | 9 |
| | Surface | 10 | 13 | 54 | 172 | 17 | 13 | 9 | 9 |
| 550 | 1 m | 9 | 19 | 40 | 58 | 11 | 10 | 10 | 10 |
| | Surface | 10 | 16 | 48 | 76 | 11 | 10 | 10 | 9 |
| 600 | 1 m | -- | 13 | 16 | 16 | 12 | 10 | 8 | 8 |
| | Surface | -- | 12 | 17 | 17 | 11 | 10 | 8 | 10 |
| 650A | 1 m | 12 | 19 | 36 | 68 | 18 | 22 | 11 | 9 |
| | Surface | 12 | 19 | 36 | 88 | 19 | 22 | 11 | 10 |
| 650B | 1 m | -- | -- | -- | -- | 18 | 14 | 13 | 10 |
| | Surface | -- | -- | -- | -- | 19 | 19 | 15 | 10 |
| 700 | 1 m | 10 | 11 | 13 | 24 | 68 | 52 | 24 | 11 |
| | Surface | 10 | 11 | 12 | 36 | 104 | 54 | 22 | 11 |
| 750 | 1 m | 10 | 10 | 10 | 14 | 8 | 9 | 19 | -- |
| | Surface | 10 | 10 | 11 | 14 | 9 | 10 | 24 | -- |
| 800 | 1 m | 9 | 10 | 12 | 19 | 8 | 9 | -- | -- |
| | Surface | 10 | 10 | 11 | 26 | 8 | 9 | -- | -- |

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TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Measurement | Exposure Rate (μR/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 15 |
| 800 | 1 m | 9 | 10 | 12 | 19 | 8 | 9 | -- | -- |
| | Surface | 10 | 10 | 11 | 26 | 8 | 9 | -- | -- |
| 850 | 1 m | 8 | 8 | 8 | 8 | 9 | 7 | -- | -- |
| | Surface | 9 | 8 | 9 | 8 | 10 | 9 | -- | -- |
| 900 | 1 m | 10 | 11 | 19 | 26 | 19 | 9 | 8 | 8 |
| | Surface | 10 | 11 | 19 | 24 | 24 | 10 | 10 | 9 |
| 950 | 1 m | 9 | 10 | 10 | 10 | 26 | 32 | 24 | 13 |
| | Surface | 8 | 11 | 10 | 11 | 38 | 38 | 28 | 14 |
| 1000 | 1 m | 10 | 11 | 24 | 32 | 24 | 16 | 10 | 8 |
| | Surface | 10 | 13 | 22 | 48 | 24 | 18 | 9 | 8 |
| 1050 | 1 m | 9 | 10 | 10 | 11 | 13 | 13 | 10 | 8 |
| | Surface | 8 | 12 | 11 | 11 | 13 | 14 | 10 | 8 |
| 1100 | 1 m | 10 | 9 | 10 | 11 | 10 | 9 | 9 | 8 |
| | Surface | 10 | 9 | 9 | 10 | 14 | 10 | 10 | 9 |
| 1150 | 1 m | 9 | 8 | 11 | 14 | 24 | 22 | 16 | 8 |
| | Surface | 8 | 8 | 10 | 16 | 28 | 17 | 13 | 9 |

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Measurement | Exposure Rate (µR/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1200 | 1 m | -- | 8 | 9 | 22 | 8 | 8 | -- | -- |
| | Surface | -- | 8 | 8 | 30 | 7 | 8 | -- | -- |
| 1250 | 1 m | 12 | 13 | 16 | 19 | 40 | 26 | 22 | 17 |
| | Surface | 12 | 14 | 16 | 34 | 40 | 28 | 22 | 17 |
| 1300 | 1 m | 16 | 19 | 24 | 92 | 96 | 68 | 64 | 22 |
| | Surface | 18 | 22 | 22 | 58 | 132 | 72 | 72 | 22 |
| 1350 | 1 m | 16 | 32 | 44 | 40 | 48 | 42 | 24 | 22 |
| | Surface | 16 | 34 | 58 | 54 | 60 | 48 | 24 | 32 |
| 1400 | 1 m | 13 | 19 | 19 | 19 | 11 | 12 | 12 | 12 |
| | Surface | 13 | 22 | 22 | 32 | 13 | 12 | 12 | 12 |
| 1450 | 1 m | 13 | 16 | 17 | 28 | 18 | 13 | 13 | 12 |
| | Surface | 14 | 17 | 17 | 28 | 38 | 13 | 13 | 13 |
| 1500 | 1 m | 16 | 44 | 58 | 38 | 28 | 34 | 30 | 16 |
| | Surface | 14 | 44 | 76 | 54 | 40 | 40 | 38 | 14 |
| 1550 | 1 m | 24 | 26 | 28 | 24 | 22 | 24 | 24 | 17 |
| | Surface | 19 | 28 | 30 | 34 | 26 | 26 | 26 | 16 |

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Measurement | Exposure Rate (μR/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1600 | 1 m | 24 | 64 | 36 | 19 | 14 | 14 | 16 | 14 |
| | Surface | 32 | 76 | 28 | 22 | 18 | 14 | 16 | 14 |
| 1650 | 1 m | 16 | 22 | 24 | 24 | 19 | 38 | 54 | 22 |
| | Surface | 17 | 24 | 26 | 30 | 28 | 42 | 68 | 28 |
| 1700 | 1 m | 24 | 40 | 72 | 38 | 19 | 18 | 16 | 13 |
| | Surface | 26 | 44 | 80 | 48 | 28 | 19 | 16 | 13 |
| 1750 | 1 m | 16 | 24 | 44 | 40 | 16 | 19 | 13 | -- |
| | Surface | 16 | 26 | 52 | 64 | 18 | 24 | 13 | -- |
| 1770 | 1 m | 16 | 19 | 16 | 16 | -- | -- | -- | -- |
| | Surface | 16 | 24 | 14 | 19 | -- | -- | -- | -- |
| 1800 | 1 m | 13 | 14 | 14 | 14 | 26 | 22 | 13 | 10 |
| | Surface | 12 | 14 | 16 | 17 | 40 | 30 | 13 | 12 |
| 1850 | 1 m | 14 | 16 | 26 | 26 | 44 | 48 | 46 | 17 |
| | Surface | 14 | 16 | 30 | 36 | 44 | 54 | 52 | 16 |
| 1900 | 1 m | 16 | 36 | 44 | 38 | 17 | 14 | 14 | 13 |
| | Surface | 16 | 40 | 48 | 60 | 24 | 15 | 13 | 13 |

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Measurement | Exposure Rate ($\mu$R/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1950 | 1 m | 16 | 38 | 44 | 34 | 50 | 40 | 19 | 14 |
| | Surface | 16 | 48 | 50 | 44 | 76 | 56 | 22 | 14 |
| 2000 | 1 m | 13 | 15 | 16 | 24 | 44 | 46 | 44 | 32 |
| | Surface | 14 | 16 | 16 | 30 | 58 | 54 | 46 | 38 |
| 2050 | 1 m | 14 | 16 | 28 | 32 | 40 | 46 | 30 | 19 |
| | Surface | 14 | 16 | 24 | 40 | 60 | 48 | -- | -- |
| 2100 | 1 m | 15 | 34 | 42 | 48 | -- | -- | -- | -- |
| | Surface | 15 | 44 | 46 | 76 | -- | -- | -- | -- |

[a] Refer to Figures 4, 5, 6, and 7.
[b] Dashes indicate inaccessible location.

TABLE 3

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF THE DUPAGE RIVER

| Upstream or Downstream Distance (m)[a] | Measurement | Exposure Rate ($\mu$R/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| Upstream: | | | | | | | | | |
| 200 | 1 m | 11 | 13 | 14 | 13 | 14 | 17 | 16 | 13 |
| | Surface | 12 | 13 | 16 | 14 | 16 | 22 | 17 | 13 |
| 150 | 1 m | 13 | 10 | 11 | 10 | 19 | 22 | 17 | 14 |
| | Surface | 13 | 10 | 13 | 10 | 22 | 22 | 17 | 16 |
| 100 | 1 m | 13 | 14 | 16 | 14 | 10 | 9 | 12 | 11 |
| | Surface | 13 | 16 | 16 | 17 | 10 | 9 | 12 | 11 |
| 50 | 1 m | 14 | 14 | 16 | 18 | 14 | 12 | 10 | 10 |
| | Surface | 16 | 16 | 16 | 22 | 17 | 13 | 11 | 11 |
| 0 | 1 m | —[b] | — | — | — | 13 | 13 | 13 | 8 |
| | Surface | — | — | — | — | 64 | 17 | 13 | 8 |
| Downstream: | | | | | | | | | |
| 50 | 1 m | 16 | 30 | 52 | 42 | 16 | 11 | 11 | 12 |
| | Surface | 17 | 32 | 54 | 52 | 16 | 13 | 11 | 13 |
| 100 | 1 m | 64 | 17 | 36 | 32 | 14 | 14 | 12 | 13 |
| | Surface | 68 | 17 | 40 | 40 | 16 | 14 | 13 | 14 |
| 150 | 1 m | 16 | 24 | 64 | 104 | 14 | 12 | 11 | 12 |
| | Surface | 16 | 24 | 88 | 136 | 17 | 13 | 13 | 13 |
| 200 | 1 m | 16 | 22 | 40 | 44 | 19 | 22 | 19 | 11 |
| | Surface | 13 | 22 | 48 | 64 | 22 | 26 | 22 | 13 |

[a] Refer to Figure 7.
[b] Inaccessible location.

TABLE 4

DIRECT RADIATION LEVELS AT LOCATIONS
IDENTIFIED BY THE WALKOVER SURFACE SCAN

| Downstream Distance (m)[a] | Distance from East(E) or West (W) Bank (m) | Exposure Rate (μR/h) | |
|---|---|---|---|
| | | Surface | 1 Meter |
| 25 | 1 W | 720 | 170 |
| 197 | 15 E | 820 | 210 |
| 205 | 12 E | 410 | 130 |
| 315 | 8 E | 33 | 35 |
| 325 | 5 E | 63 | 49 |
| 401 | 7 W | 210 | 84 |
| 410 | 1 E | 185 | 76 |
| 465 | 1 E | 84 | 43 |
| 585 | 2 E | 210 | 155 |
| 620 | 0.5 E | 170 | 80 |
| 760 | 1 W | 18 | 18 |
| 765 | 1 W | 145 | 31 |
| 765 | 3 E | 190 | 105 |
| 775 | 1 W | 105 | 61 |
| 790 | 2 E | 125 | 63 |
| 889 | 2 E | 70 | 31 |
| 1030 | 3 E | 115 | 59 |
| 1280 | 1 W | 105 | 74 |
| 1325 | 4 W | 93 | 76 |
| 1340 | 1 W | 240 | 110 |
| 1598 | 6 W | 93 | 74 |
| 1665 | 5 E | 135 | 120 |
| 1687 | 1 E | 210 | 135 |
| 1715 | 1 W | 190 | 140 |
| 1810 | 1 W | 130 | 84 |
| 1870 | 1 E | 130 | 85 |
| 1970 | 1 E | 130 | 53 |
| 1975 | 4 W | 105 | 88 |
| 1980 | 20 W | 130 | 72 |
| 2006 | 1 E | 210 | 95 |
| 2030 | 1 W | 80 | 63 |

[a] Refer to Figures 8, 9, 10, and 11.

TABLE 5

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) [a] | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 50 | Surface | —[b] | — | — | 46.6 | 28.4 | 13.4 | 19.9 | 29.1 |
| | 15 | — | — | — | 121 | 38.9 | 12.2 | 24.0 | 9.14 |
| | 30 | — | — | — | 101 | 23.3 | 9.98 | 27.7 | 3.34 |
| | 45 | — | — | — | — | — | 11.1 | — | — |
| | 60 | — | — | — | 20.0 | 7.33 | — | 76.6 | — |
| | 70 | — | — | — | 13.6 | 7.89 | — | — | — |
| | 90 | — | — | — | — | — | — | 169 | — |
| | 110 | — | — | — | — | — | — | 226 | — |
| | 130 | — | — | — | — | — | — | 176 | — |
| | 150 | — | — | — | — | — | — | 46.8 | — |
| | 170 | — | — | — | — | — | — | 23.5 | — |
| 100 | Surface | — | 11.6 | 7.07 | — | 30.0 | 41.8 | 45.2 | 3.17 |
| | 15 | — | 28.5 | 9.26 | — | 14.8 | 38.8 | 32.9 | 5.38 |
| | 30 | — | 30.0 | 7.39 | — | 8.90 | 17.5 | 18.2 | 4.83 |
| | 60 | — | — | 8.99 | — | 5.65 | 6.38 | 7.22 | 5.49 |
| | 70 | — | — | — | — | 6.10 | — | — | — |
| | 75 | — | — | — | — | — | — | 8.10 | — |
| | 80 | — | — | — | — | — | 6.99 | — | — |
| 150 | Surface | — | 8.01 | 9.47 | 8.66 | 3.32 | 23.1 | 16.8 | — |
| | 15 | — | 12.9 | 25.6 | 14.6 | 2.50 | 42.4 | 24.6 | — |
| | 30 | — | 9.50 | 46.7 | 25.2 | 3.56 | 41.8 | 25.6 | — |
| | 50 | — | — | — | — | 5.25 | — | — | — |
| | 60 | — | 20.3 | 41.1 | 66.5 | — | 33.5 | 27.7 | — |
| | 80 | — | — | — | — | — | — | 35.8 | — |
| | 90 | — | 63.7 | 41.6 | 68.5 | — | — | — | — |
| | 100 | — | — | — | 51.4 | — | — | — | — |

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 200 | Surface | — | — | 25.5 | 39.9 | 37.9 | 51.5 | 166 | 22.7 |
| | 15 | — | — | 44.6 | 51.1 | 44.2 | 40.4 | 261 | 37.4 |
| | 30 | — | — | 54.5 | 23.5 | 35.4 | 32.3 | 296 | 23.0 |
| | 60 | — | — | 24.1 | 17.3 | 13.0 | 15.0 | 193 | 9.68 |
| | 70 | — | — | — | — | — | 7.42 | — | 9.32 |
| | 80 | — | — | — | 11.1 | — | — | — | — |
| | 90 | — | — | 11.3 | — | — | — | 51.7 | — |
| | 100 | — | — | — | — | — | — | 25.4 | — |
| 250 | Surface | — | — | — | 49.5 | 8.01 | 5.63 | 21.1 | 9.20 |
| | 15 | — | — | — | 32.8 | 5.99 | 10.3 | 33.3 | 16.9 |
| | 30 | — | — | — | 14.7 | 2.34 | 15.1 | 44.3 | 24.8 |
| | 40 | — | — | — | 9.17 | — | — | — | — |
| | 45 | — | — | — | — | 2.34 | — | — | — |
| | 60 | — | — | — | — | — | — | 12.2 | 14.2 |
| | 70 | — | — | — | — | — | 3.22 | — | — |
| | 75 | — | — | — | — | — | — | 9.74 | — |
| | 80 | — | — | — | — | — | — | — | 9.14 |
| 300 | Surface | — | — | — | 25.7 | 5.16 | 22.4 | 19.6 | 5.02 |
| | 15 | — | — | — | 49.5 | 10.9 | 28.3 | 21.4 | 5.10 |
| | 30 | — | — | — | 66.1 | 12.0 | 20.2 | 21.0 | 6.13 |
| | 60 | — | — | — | 71.3 | 5.32 | 7.54 | 7.1 | 6.99 |
| | 75 | — | — | — | — | — | 3.89 | — | 6.38 |
| | 80 | — | — | — | 55.0 | — | — | — | — |
| | 90 | — | — | — | — | 2.59 | — | — | — |

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 350 | Surface | — | — | — | 76.2 | 9.17 | — | — | — |
| | 15 | — | — | — | 116 | 8.63 | — | — | — |
| | 30 | — | — | — | 93.5 | 4.10 | — | — | — |
| | 50 | — | — | — | 34.4 | 2.68 | — | — | — |
| 400 | Surface | 4.65 | 55.1 | 32.8 | 11.8 | 74.2 | — | — | — |
| | 15 | 5.65 | 125 | 27.6 | 8.72 | 74.8 | — | — | — |
| | 30 | 7.10 | 163 | 24.2 | 5.13 | 29.8 | — | — | — |
| | 60 | 7.36 | 21.9 | 14.2 | 1.86 | 10.1 | — | — | — |
| | 80 | 9.95 | — | 8.04 | — | — | — | — | — |
| | 90 | — | 12.1 | — | — | — | — | — | — |
| | 100 | — | 10.0 | — | — | — | — | — | — |
| 450 | Surface | 4.20 | 3.51 | 3.05 | 64.7 | 18.4 | 5.05 | — | — |
| | 15 | 6.07 | 6.16 | 4.36 | 102 | 31.2 | 6.44 | — | — |
| | 30 | 6.33 | 7.89 | 3.74 | 79.7 | 28.4 | 5.30 | — | — |
| | 40 | 6.84 | — | — | — | — | — | — | — |
| | 45 | — | — | 3.32 | 30.2 | — | — | — | — |
| | 60 | 4.81 | 5.96 | — | — | 2.68 | 15.8 | — | — |
| | 70 | — | — | — | — | — | 18.6 | — | — |
| | 80 | — | 4.59 | — | — | — | — | — | — |
| 500 | Surface | 3.37 | 3.97 | 69.8 | 156 | — | — | — | 3.76 |
| | 15 | 4.86 | 4.97 | 111 | 251 | — | — | — | 4.75 |
| | 30 | 4.97 | 2.79 | 106 | 150 | — | — | — | 4.25 |
| | 60 | 6.16 | 1.41 | 14.5 | 14.5 | — | — | — | 3.74 |
| | 80 | 6.84 | — | 3.64 | 5.57 | — | — | — | — |
| | 90 | — | — | — | — | — | — | — | 4.28 |

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TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 550 | Surface | 3.17 | 8.54 | 46.2 | 118 | 5.30 | — | 3.47 | 3.34 |
| | 15 | 3.84 | 11.1 | 3.65 | 222 | 4.20 | — | — | — |
| | 30 | 4.78 | 5.02 | 43.5 | 354 | 3.94 | — | 4.94 | 4.83 |
| | 50 | — | 1.27 | — | — | — | — | — | — |
| | 60 | 4.38 | — | 8.21 | 35.5 | 1.90 | — | 2.15 | 4.75 |
| | 70 | 4.49 | — | — | — | 2.04 | — | — | — |
| | 80 | — | — | 2.61 | — | — | — | — | — |
| 600 | Surface | — | 4.05 | 5.38 | 5.65 | 4.89 | 3.05 | 3.17 | 2.61 |
| | 15 | — | 4.41 | 5.54 | 8.57 | — | — | — | — |
| | 30 | — | 4.44 | 1.43 | 6.3 | 4.30 | 3.34 | 3.51 | 5.41 |
| | 60 | — | 4.86 | 2.70 | 2.45 | 4.28 | 1.77 | 1.45 | 6.47 |
| | 75 | — | — | 1.45 | 1.36 | — | — | — | — |
| 650 (W & Ea) | Surface | 2.41 | 9.77 | 25.8 | 102 | 26.3 | 13.7 | 5.43 | 4.05 |
| | 15 | 4.20 | 11.6 | 34.5 | 173 | 25.7 | — | — | — |
| | 30 | 4.62 | 6.16 | 12.5 | 220 | | | | |
| | 60 | 4.46 | 2.00 | 2.30 | 45.9 | 3.61 | 2.08 | 4.41 | 5.24 |
| | 70 | — | — | — | 29.7 | 2.45 | — | 2.33 | — |
| | 75 | — | 1.70 | — | — | — | 1.41 | — | — |
| | 90 | 4.30 | — | — | — | — | — | — | — |
| 650 (Eb) | Surface | — | — | — | — | 26.3 | 7.51 | 7.45 | 2.96 |
| | 15 | — | — | — | — | 25.7 | — | — | — |
| | 30 | | | | | 8.33 | 11.7 | 5.71 | 6.47 |
| | 60 | — | — | — | — | 3.61 | 3.51 | 4.73 | 4.02 |
| | 70 | — | — | — | — | 2.45 | — | 2.54 | 3.34 |
| 700 | Surface | 1.36 | 2.68 | 2.91 | 38.4 | 133 | 47.1 | 8.15 | 3.05 |
| | 15 | 2.41 | 3.71 | 2.86 | 75.3 | 186 | 79.4 | — | — |

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TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| | 30 | 1.60 | 2.98 | 47.5 | 133 | 79.6 | 47.4 | 5.05 | 7.28 |
| | 45 | -- | -- | 0.57 | -- | -- | -- | -- | -- |
| | 50 | -- | -- | -- | -- | -- | | | |
| | 60 | 0.49 | -- | -- | 31.3 | -- | -- | 1.30 | 5.46 |
| | 70 | 0.60 | -- | -- | -- | -- | -- | -- | -- |
| | 80 | -- | -- | -- | -- | -- | -- | -- | 3.82 |
| 750 | Surface | 2.54 | 2.15 | 3.12 | 13.2 | 20.8 | 2.45 | 3.42 | -- |
| | 15 | 4.46 | 4.54 | 4.15 | 18.1 | 12.5 | -- | 5.90 | -- |
| | 30 | 4.73 | 5.99 | 5.65 | 52.4 | 6.16 | 2.15 | 7.48 | -- |
| | 40 | -- | -- | -- | -- | 5.32 | -- | -- | -- |
| | 60 | 1.73 | 4.73 | 2.41 | 22.8 | -- | -- | 7.39 | -- |
| | 70 | 0.73 | 3.10 | -- | 5.88 | -- | -- | 5.99 | -- |
| 800 | Surface | 3.29 | 3.03 | 6.61 | 25.5 | 4.38 | 3.42 | -- | -- |
| | 15 | 3.94 | 4.57 | 8.39 | 35.0 | -- | -- | -- | -- |
| | 30 | 6.61 | 5.65 | 10.1 | 35.3 | 9.62 | 4.62 | -- | -- |
| | 45 | 4.89 | -- | -- | -- | -- | -- | -- | -- |
| | 60 | -- | 4.97 | 1.06 | 10.4 | 3.42 | 2.98 | -- | -- |
| | 70 | -- | -- | 1.00 | -- | -- | 2.15 | -- | -- |
| | 75 | -- | 5.54 | -- | -- | 2.23 | -- | -- | -- |
| 850 | Surface | 3.07 | 4.53 | 2.30 | 3.51 | 7.57 | 3.64 | -- | -- |
| | 15 | 6.73 | 5.00 | 4.44 | 4.70 | 12.0 | -- | -- | -- |
| | 30 | 6.58 | 6.49 | 6.16 | 4.97 | 22.0 | 5.60 | -- | -- |
| | 60 | 7.44 | 7.85 | 6.73 | 5.71 | 59.0 | 5.02 | -- | -- |
| | 70 | -- | -- | -- | -- | -- | 2.79 | -- | -- |
| | 90 | 6.25 | 6.54 | 6.13 | 3.71 | 95.6 | -- | -- | -- |
| | 110 | -- | -- | -- | -- | 26.6 | -- | -- | -- |
| | 120 | -- | -- | -- | -- | 7.95 | -- | -- | -- |

## TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
## BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| | 130 | -- | -- | -- | -- | 6.67 | -- | -- | -- |
| 900 | Surface | 3.64 | 2.96 | 5.35 | 48.3 | 18.6 | 3.51 | 1.72 | 2.98 |
| | 15 | -- | -- | -- | 83.4 | 40.9 | 4.81 | -- | -- |
| | 30 | 5.82 | 2.70 | 7.36 | 10.9 | 32.2 | 4.83 | 2.45 | 4.86 |
| | 60 | 6.44 | 2.59 | 1.34 | 26.2 | 5.13 | 4.92 | 3.82 | 5.08 |
| | 70 | -- | -- | 1.41 | -- | -- | 3.87 | 6.70 | 5.05 |
| | 90 | 6.50 | -- | -- | -- | -- | -- | -- | -- |
| 950 | Surface | 4.10 | 4.41 | 3.97 | 4.23 | 44.3 | 30.2 | 19.3 | 5.27 |
| | 15 | -- | -- | -- | -- | 77.9 | 59.1 | 27.9 | -- |
| | 30 | 9.86 | 7.51 | 6.76 | 6.27 | 41.6 | 24.6 | 12.7 | 2.93 |
| | 60 | 6.07 | 9.65 | 7.30 | 6.47 | 8.99 | 5.49 | 2.43 | 1.08 |
| | 70 | -- | -- | -- | 5.63 | -- | 3.76 | -- | -- |
| | 75 | -- | -- | 5.96 | -- | -- | -- | -- | -- |
| | 90 | -- | 9.44 | -- | -- | -- | -- | -- | -- |
| 1000 | Surface | 2.54 | 4.20 | 14.0 | 59.1 | 19.6 | 6.70 | 3.54 | 4.23 |
| | 15 | -- | -- | 17.7 | 78.2 | -- | -- | -- | -- |
| | 30 | 5.21 | 4.12 | 7.98 | 53.0 | 14.7 | 4.94 | 3.56 | 5.46 |
| | 50 | -- | -- | -- | -- | -- | -- | 1.54 | --- |
| | 60 | 6.02 | 1.24 | 1.94 | 6.24 | 3.03 | 1.27 | -- | 3.64 |
| | 65 | -- | -- | 1.68 | -- | -- | -- | -- | -- |
| | 70 | -- | 1.16 | -- | -- | -- | -- | -- | -- |
| | 75 | -- | -- | -- | -- | -- | -- | -- | 3.15 |
| | 90 | 5.46 | -- | -- | -- | -- | -- | -- | -- |
| 1050 | Surface | 2.82 | 2.56 | 4.10 | 4.62 | 14.1 | 6.70 | 2.47 | 2.15 |
| | 30 | 6.33 | 7.57 | 7.22 | 4.30 | 18.8 | 11.8 | 5.74 | 3.69 |
| | 60 | 7.07 | 7.74 | 8.21 | 8.10 | 3.39 | 3.00 | 4.15 | 2.32 |

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| | 70 | — | — | 7.95 | 6.81 | — | — | — | — |
| | 75 | 7.85 | — | — | — | 3.89 | — | — | — |
| | 80 | — | 7.01 | — | — | — | — | — | — |
| 1100 | Surface | 3.59 | 3.44 | 3.47 | 5.00 | 7.39 | 2.25 | 2.41 | 1.68 |
| | 30 | 7.36 | 8.96 | 4.36 | 5.41 | 5.02 | 1.94 | 4.78 | 3.32 |
| | 40 | — | — | 4.10 | — | — | — | — | — |
| | 60 | 8.69 | 9.05 | — | 4.38 | 1.54 | 0.94 | 3.37 | 1.32 |
| | 75 | — | — | — | — | — | — | 0.91 | — |
| | 90 | 7.63 | — | — | — | — | — | — | 1.04 |
| 1150 | Surface | 3.59 | 1.41 | 3.89 | 10.2 | 61.1 | 20.4 | 4.46 | 1.84 |
| | 30 | 7.10 | 3.99 | 3.07 | 6.38 | 78.9 | 13.3 | 4.70 | 3.59 |
| | 60 | 8.75 | 2.61 | 3.29 | 1.72 | 13.1 | 6.19 | 1.79 | 1.58 |
| | 70 | 10.2 | — | — | 1.06 | — | 5.49 | — | — |
| | 75 | — | — | 3.71 | — | — | — | 0.98 | 1.37 |
| | 80 | — | — | — | — | 9.29 | — | — | — |
| 1200 | Surface | — | 2.39 | 2.10 | 4.94 | 7.60 | — | — | — |
| | 30 | — | 5.32 | 2.93 | 6.56 | 11.1 | — | — | — |
| | 60 | — | 2.32 | 3.24 | 8.10 | 14.7 | — | — | — |
| | 75 | — | — | 4.59 | 7.80 | — | — | — | — |
| | 90 | — | — | — | — | 16.0 | — | — | — |
| 1250 | Surface | 4.75 | 2.98 | 2.71 | 11.2 | 2.23 | — | — | — |
| | 15 | 6.01 | 3.75 | 3.68 | 16.6 | 2.79 | — | — | — |
| | 30 | 4.84 | 3.91 | 4.36 | 30.3 | 2.36 | — | — | — |
| | 60 | 3.18 | 2.35 | 4.10 | 21.5 | 2.07 | — | — | — |

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1300 | Surface | 2.95 | 12.2 | 3.69 | 46.2 | 7.08 | 2.22 | 1.85 | -- |
| | 15 | 5.03 | 7.42 | 3.77 | 77.4 | 9.35 | 3.09 | 3.04 | -- |
| | 30 | 3.27 | 17.8 | 2.93 | 69.7 | 7.34 | 3.25 | 3.65 | -- |
| | 60 | 1.46 | 80.3 | 1.58 | 9.07 | 2.08 | 2.13 | 3.49 | -- |
| | 70 | -- | -- | -- | -- | 2.24 | -- | -- | -- |
| | 90 | 1.45 | 9.88 | 1.38 | -- | -- | -- | 3.39 | -- |
| 1350 | Surface | 3.17 | 9.31 | 20.5 | 30.1 | 2.16 | 2.17 | 2.36 | 2.07 |
| | 15 | 3.71 | 12.9 | 27.3 | 38.0 | 2.37 | 2.58 | 2.92 | 2.78 |
| | 30 | 3.46 | 10.6 | 24.3 | 93.3 | 2.97 | 4.00 | 4.45 | 3.86 |
| | 60 | 1.64 | 3.51 | 4.86 | 52.3 | 2.75 | 4.50 | 5.76 | 4.47 |
| | 65 | -- | -- | -- | 30.0 | -- | -- | -- | -- |
| | 80 | -- | -- | 3.37 | -- | -- | -- | -- | -- |
| | 90 | -- | 1.95 | -- | -- | 2.83 | 4.07 | 5.16 | 3.04 |
| 1400 | Surface | 2.13 | 5.30 | 5.24 | 8.88 | 1.88 | 2.24 | 2.16 | -- |
| | 15 | 2.39 | 5.89 | 5.11 | 11.8 | 1.72 | 2.41 | 3.63 | -- |
| | 30 | 1.34 | 5.65 | 4.20 | 11.0 | 1.42 | 3.81 | 4.74 | -- |
| | 60 | 1.31 | 1.36 | 1.84 | 3.01 | 14.3 | 3.15 | 5.00 | -- |
| | 70 | -- | 1.38 | -- | -- | -- | -- | -- | -- |
| | 80 | -- | -- | 1.74 | 1.61 | -- | -- | -- | -- |
| | 90 | -- | -- | -- | -- | 2.46 | 2.37 | 2.57 | -- |
| 1450 | Surface | 2.86 | 3.90 | 3.54 | 6.44 | 2.87 | 1.31 | 1.67 | 2.12 |
| | 15 | 2.87 | 4.55 | 3.89 | 7.93 | 2.63 | 1.60 | 1.77 | 2.95 |
| | 30 | 3.31 | 5.57 | 3.99 | 6.54 | 3.30 | 1.72 | 2.82 | 4.06 |
| | 60 | 2.03 | 2.30 | 1.09 | 1.69 | 1.69 | 1.39 | 3.20 | 4.96 |
| | 75 | -- | -- | -- | -- | 2.62 | -- | -- | -- |
| | 80 | -- | -- | -- | 1.15 | -- | -- | -- | -- |
| | 90 | 1.29 | 1.31 | -- | -- | -- | 1.48 | 2.93 | 4.57 |

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## TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
## BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1500 | Surface | 2.58 | 22.8 | 30.9 | 34.3 | 14.6 | 14.9 | 15.8 | — |
| | 15 | 2.84 | 33.1 | 42.2 | 50.9 | 21.3 | 17.7 | 19.4 | -- |
| | 30 | 2.70 | 32.5 | 46.9 | 104 | 25.4 | 15.3 | 13.5 | — |
| | 60 | 1.31 | 5.83 | 5.16 | 39.6 | 4.70 | 4.57 | 2.65 | -- |
| | 70 | — | -- | — | 13.6 | -- | — | -- | -- |
| | 75 | — | 2.69 | 3.45 | -- | -- | -- | -- | -- |
| | 80 | 1.33 | — | — | — | 1.50 | 2.45 | — | — |
| 1550 | Surface | 6.98 | 7.36 | 6.91 | 10.9 | 8.31 | 10.5 | 7.52 | 1.72 |
| | 15 | 11.6 | 8.38 | 11.0 | 16.4 | 10.4 | 15.8 | 10.3 | 4.92 |
| | 30 | 9.63 | 7.63 | 12.6 | 14.9 | 7.96 | 16.9 | 13.4 | 3.30 |
| | 60 | 2.53 | 2.33 | 2.44 | 3.07 | 1.84 | 6.18 | 2.18 | 4.20 |
| | 75 | — | -- | — | — | -- | -- | 1.48 | -- |
| | 80 | — | -- | -- | -- | -- | 3.03 | -- | -- |
| | 90 | 2.14 | 1.89 | — | -- | -- | -- | — | 4.43 |
| 1600 | Surface | 6.98 | 38.3 | 11.8 | 5.29 | 1.74 | 1.79 | 1.64 | 4.17 |
| | 15 | 11.6 | 56.3 | 16.2 | 7.75 | 2.16 | 2.19 | 4.91 | 1.77 |
| | 30 | 9.63 | 79.3 | 27.0 | 5.92 | 2.93 | 2.87 | 4.13 | 2.34 |
| | 60 | 2.53 | 7.92 | 48.9 | 3.35 | 3.04 | 3.20 | 4.17 | 3.25 |
| | 90 | 2.14 | 3.42 | 7.09 | -- | 2.84 | 3.01 | -- | 3.67 |
| 1650 | Surface | 3.47 | 5.35 | 5.89 | 8.29 | 5.26 | 18.0 | 29.1 | 3.38 |
| | 15 | 3.64 | 6.98 | 6.57 | 11.7 | 6.96 | 25.0 | 45.4 | 4.95 |
| | 30 | 4.17 | 5.82 | 5.2 | 10.1 | 8.31 | 42.9 | 86.1 | 3.64 |
| | 60 | 3.51 | 3.73 | 2.59 | 3.10 | 3.54 | 53.9 | 23.8 | 2.70 |
| | 80 | — | -- | -- | -- | -- | 50.5 | — | -- |
| | 90 | 2.88 | 2.57 | 2.42 | 1.91 | 3.00 | -- | 4.11 | 2.61 |

### TABLE 5, cont.

### TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1700 | Surface | 6.23 | 15.8 | 40.6 | 46.6 | 6.17 | 2.12 | 1.43 | 1.22 |
| | 15 | 7.62 | 22.8 | 64.1 | 21.4 | 8.52 | 3.13 | 2.33 | 1.97 |
| | 30 | 6.64 | 19.8 | 90.2 | 12.7 | 6.85 | 2.74 | 2.68 | 2.33 |
| | 60 | 2.80 | 4.04 | 19.9 | 3.7 | 5.21 | 2.78 | 2.82 | 2.86 |
| | 90 | 1.92 | 2.47 | 4.36 | 20.5 | 4.50 | 2.6 | 2.59 | 3.12 |
| 1750 | Surface | 3.11 | 5.75 | 20.2 | 43.7 | 3.71 | 5.15 | 1.27 | — |
| | 15 | 3.85 | 7.04 | 30.1 | 82.2 | 4.88 | 9.58 | 1.53 | — |
| | 30 | 3.51 | 5.36 | 21.0 | 140 | 3.72 | 21.7 | 1.93 | — |
| | 60 | 3.24 | 3.14 | 3.79 | 555 | 4.11 | 59.4 | 1.41 | — |
| | 90 | 3.03 | 2.92 | 2.50 | 357 | 3.15 | 9.26 | 2.06 | — |
| 1770 | Surface | 2.70 | 8.31 | 3.17 | 5.91 | — | — | — | — |
| | 15 | 3.76 | 9.75 | 3.67 | 8.79 | — | — | — | — |
| | 30 | 3.87 | 12.7 | 4.27 | 9.64 | — | — | — | — |
| | 60 | 3.44 | 20.6 | 5.71 | 9.62 | — | — | — | — |
| | 90 | 2.85 | 4.10 | — | — | — | — | — | — |
| 1800 | Surface | 2.47 | 2.14 | 3.09 | 4.55 | 14.6 | 8.40 | 2.75 | 2.18 |
| | 15 | 2.53 | 2.71 | 3.84 | 6.26 | 19.0 | 12.5 | 3.04 | 2.27 |
| | 30 | 3.22 | 2.78 | 5.52 | 5.98 | 31.1 | 17.2 | 3.42 | 2.78 |
| | 60 | 3.30 | 2.48 | 5.48 | 3.09 | 10.7 | 19.1 | 2.97 | 1.91 |
| | 75 | 3.59 | — | 5.92 | 2.94 | 7.59 | — | — | — |
| | 80 | — | — | — | — | — | 9.59 | — | — |
| | 90 | — | — | — | — | — | — | — | 1.88 |

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| 1850 | Surface | 2.45 | 2.33 | 8.82 | 9.21 | 41.9 | 34.5 | 21.7 | 3.34 |
| | 15 | 3.14 | 3.35 | 11.2 | 14.0 | 60.4 | 36.1 | 26.3 | 3.69 |
| | 30 | 3.78 | 2.96 | 9.21 | 15.6 | 107 | 40.2 | 18.1 | 3.19 |
| | 60 | 3.25 | 2.62 | 3.26 | 4.33 | 32.7 | 6.23 | 4.99 | 2.85 |
| | 80 | — | — | — | — | 10.0 | — | — | — |
| | 85 | — | — | — | — | — | 2.92 | — | — |
| | 90 | — | 1.82 | 3.18 | 2.69 | — | — | — | 2.47 |
| 1900 | Surface | 2.62 | 13.8 | 19.5 | 40.3 | 4.63 | 2.09 | 2.22 | 2.54 |
| | 15 | 3.46 | 19.7 | 30.4 | 58.4 | 4.96 | 2.76 | 2.42 | 3.19 |
| | 30 | 5.75 | 18.2 | 32.3 | 107 | 4.25 | 3.27 | 2.60 | 3.47 |
| | 60 | 3.82 | 5.49 | 5.80 | 62.7 | 4.26 | 3.49 | 3.34 | 2.98 |
| | 70 | — | — | — | — | 3.55 | — | — | — |
| | 85 | — | — | — | — | — | 3.16 | 3.60 | — |
| | 90 | 2.58 | 2.55 | 3.97 | 17.7 | — | — | — | — |
| 1950 | Surface | 2.35 | 20.0 | 20.6 | 14.0 | 60.5 | 17.1 | 5.44 | 2.25 |
| | 15 | 2.78 | 29.6 | 29.2 | 24.6 | 93.1 | 24.7 | 6.11 | 2.91 |
| | 30 | 3.81 | 31.2 | 24.5 | 23.8 | 154 | 22.9 | 5.02 | 3.99 |
| | 60 | 3.12 | 5.93 | 4.40 | 5.81 | 20.2 | 4.69 | 4.49 | 4.10 |
| | 75 | — | — | — | — | 11.0 | — | — | — |
| | 80 | — | — | — | 3.12 | — | — | — | — |
| | 90 | 2.33 | 3.12 | 2.75 | — | — | 2.39 | 2.85 | 3.73 |
| 2000 | Surface | — | 2.51 | 2.79 | 10.1 | 28.7 | 21.1 | 18.5 | 13.3 |
| | 15 | 3.44 | 3.17 | 3.00 | 15.2 | 42.5 | 29.4 | 26.6 | 17.5 |
| | 30 | 4.45 | 3.70 | 4.28 | 23.6 | 89.4 | 31.5 | 38.0 | 15.1 |

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| | 60 | 4.53 | 4.20 | 4.15 | 9.16 | 33.2 | 6.58 | 11.0 | 4.06 |
| | 65 | — | — | 3.65 | — | — | — | — | — |
| | 70 | — | — | — | 5.26 | — | — | — | — |
| 2050 | Surface | 2.67 | 3.05 | 6.08 | 31.1 | 44.6 | 21.2 | 14.1 | 4.14 |
| | 15 | 3.31 | 3.01 | 7.29 | 41.3 | 58.6 | 29.8 | 20.2 | 5.78 |
| | 30 | 4.37 | 3.87 | 5.89 | 94.8 | 59.0 | 28.1 | 16.3 | 7.13 |
| | 40 | — | — | 3.35 | — | — | — | — | — |
| | 60 | 3.72 | 3.39 | — | 139 | 8.44 | 4.68 | 4.50 | 2.07 |
| | 75 | — | — | — | — | 4.62 | — | — | — |
| | 80 | — | — | — | — | — | 3.40 | — | — |
| | 85 | — | — | — | 30.2 | — | — | — | — |
| | 90 | 2.51 | 2.13 | — | — | — | — | 3.71 | — |
| 2100 | Surface | 2.32 | 19.0 | 26.0 | 28.5 | 5.4 | — | — | — |
| | 15 | 3.21 | 29.3 | 41.5 | 43.2 | 7.46 | — | — | — |
| | 30 | 4.30 | 30.0 | 101 | 71.4 | 11.5 | — | — | — |
| | 60 | 3.92 | 5.91 | 17.3 | 27.3 | 7.40 | — | — | — |
| | 85 | — | — | 8.72 | — | 3.14 | — | — | — |
| | 90 | 2.09 | 2.70 | — | 9.15 | — | — | — | — |

[a] Refer to Figures 8, 9, 10, and 11.
[b] Dash indicates inaccessible location, impenetrable rocks, etc.

TABLE 6

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

| Upstream or Downstream Distance (m)[a] | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| Upstream: | | | | | | | | | |
| 200 | Surface | 1.74 | 2.92 | 3.07 | 2.87 | 3.60 | 6.23 | 3.31 | 2.31 |
| | 15 | 2.87 | 3.50 | 3.79 | 3.87 | 4.71 | 0.71 | 4.55 | 2.92 |
| | 30 | 3.36 | 7.49 | 4.28 | 4.67 | 7.16 | 11.9 | 5.59 | 3.00 |
| | 60 | 2.71 | 2.65 | 2.86 | 3.52 | 9.61 | 7.11 | 2.88 | 2.78 |
| | 90 | 2.04 | 1.88 | 1.96 | 2.84 | 5.51 | 2.39 | 1.5 | 2.09 |
| 150 | Surface | 2.21 | 1.64 | 2.00 | 1.51 | 6.80 | 7.11 | 3.73 | 1.58 |
| | 15 | 2.33 | 2.33 | 2.61 | 2.5 | 11.2 | 12.6 | 6.33 | 1.98 |
| | 30 | 2.91 | 2.51 | 3.15 | 2.55 | 24.8 | 25.4 | 2.55 | 2.00 |
| | 60 | 3.48 | 3.21 | 3.37 | 2.79 | 13.4 | 5.84 | 2.48 | 1.72 |
| | 75 | --[b] | -- | -- | -- | -- | -- | -- | -- |
| | 90 | 2.92 | 3.42 | 3.74 | 3.29 | 4.80 | 2.09 | -- | 1.37 |
| 100 | Surface | 2.06 | 2.63 | 3.12 | 3.59 | 2.20 | 1.35 | 2.15 | 1.92 |
| | 15 | 2.34 | 3.23 | 4.00 | 4.42 | 2.34 | 1.45 | 2.87 | 3.13 |
| | 30 | 2.86 | 3.73 | 4.67 | 5.39 | 2.28 | 1.74 | 3.68 | 3.83 |
| | 60 | 3.06 | 3.18 | 3.15 | 3.84 | 1.50 | 1.87 | 1.84 | 3.91 |
| | 70 | -- | -- | -- | -- | 1.60 | -- | -- | -- |
| | 80 | -- | -- | -- | -- | -- | 2.19 | -- | 3.00 |
| | 90 | 3.19 | 2.27 | 2.95 | 2.55 | -- | -- | -- | -- |
| 50 | Surface | 1.97 | 2.25 | 2.50 | 5.00 | 3.46 | 1.84 | 1.55 | 1.83 |
| | 15 | 2.53 | 2.85 | 2.96 | 7.55 | 4.62 | 2.18 | 1.92 | 1.84 |
| | 30 | 3.32 | 3.28 | 3.70 | 11.9 | 7.61 | 2.80 | 1.97 | 2.05 |
| | 40 | -- | -- | -- | -- | -- | -- | -- | -- |
| | 60 | 2.84 | 3.34 | 3.04 | 4.80 | 3.91 | 1.60 | 1.65 | -- |

TABLE 6, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

| Upstream or Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
| **Upstream cont.:** | | | | | | | | | |
| 50 | 80 | 1.69 | — | — | — | — | — | — | — |
| | 85 | — | — | — | 1.95 | — | — | — | — |
| | 90 | — | 2.72 | 3.84 | — | 2.08 | 1.55 | 1.42 | — |
| 0 | Surface | — | — | — | — | 2.03 | 2.56 | 2.33 | 2.68 |
| | 15 | — | — | — | — | 2.42 | 2.99 | 2.86 | 3.80 |
| | 30 | — | — | — | — | 5.19 | 2.99 | 4.87 | 3.00 |
| | 60 | — | — | — | — | 2.41 | 3.69 | 3.05 | 2.42 |
| | 80 | — | — | — | — | — | — | — | 1.78 |
| | 90 | — | — | — | — | — | 3.53 | 1.74 | — |
| **Downstream:** | | | | | | | | | |
| 50 | Surface | 33.8 | 33.0 | 7.51 | 2.85 | 2.71 | 1.66 | 1.64 | 2.01 |
| | 15 | 47.1 | 48.9 | 9.35 | 3.34 | 3.71 | 2.23 | 1.53 | 3.13 |
| | 30 | 91.8 | 93.8 | 7.89 | 3.67 | 6.47 | 2.85 | 1.52 | 3.71 |
| | 60 | 249 | 133 | 4.16 | 3.83 | 3.42 | 1.71 | 1.83 | 2.89 |
| | 70 | — | — | — | — | — | — | — | 2.41 |
| | 85 | 85.3 | — | — | — | — | — | — | — |
| | 90 | — | 15.0 | 3.31 | 4.02 | 1.71 | 1.50 | — | — |
| 100 | Surface | 2.32 | 60.8 | 17.3 | 14.5 | 2.66 | 1.86 | 1.87 | 2.19 |
| | 15 | 2.96 | 14.4 | 22.4 | 18.7 | 3.51 | 1.84 | 2.20 | 2.55 |
| | 30 | 3.69 | 49.7 | 33.9 | 31.4 | 2.71 | 2.27 | 2.89 | 3.21 |
| | 60 | 4.23 | 18.3 | 111 | 55.1 | 1.54 | 1.44 | 2.31 | 3.30 |
| | 80 | — | — | — | — | — | — | 1.45 | 2.12 |

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TABLE 6, cont.

## TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
## BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

| Upstream or Downstream Distance (m) | Depth (cm) | Total Thorium (pCi/g) | | | | | | | |
| | | Distance from West Bank (m) | | | | Distance from East Bank (m) | | | |
| | | 25 | 10 | 5 | 1 | 1 | 5 | 10 | 25 |
|---|---|---|---|---|---|---|---|---|---|
| Downstream cont.: | | | | | | | | | |
| 100 | 85 | -- | 2.32 | 29.7 | -- | -- | -- | -- | -- |
| | 90 | 2.82 | -- | -- | 52.6 | -- | 1.65 | -- | -- |
| 150 | Surface | 2.68 | 6.15 | 17.0 | 28.1 | 4.61 | 7.73 | 3.81 | 2.49 |
| | 15 | 2.75 | 7.56 | 23.1 | 63.3 | 3.47 | 2.61 | 2.98 | 2.55 |
| | 30 | 3.39 | 7.89 | 17.3 | 96.7 | 3.32 | 3.43 | 3.90 | 3.59 |
| | 60 | 3.86 | 2.52 | 7.82 | 12.6 | 1.79 | 3.65 | 4.29 | 3.96 |
| | 85 | 3.83 | -- | -- | 3.27 | -- | -- | 3.06 | -- |
| | 90 | -- | -- | 4.01 | -- | -- | 3.34 | -- | 3.09 |
| 200 | Surface | 2.39 | 4.57 | 14.7 | 28.1 | 4.61 | 7.73 | 3.81 | 2.49 |
| | 15 | 2.91 | 5.49 | 24.1 | 41.8 | 7.13 | 12.5 | 6.08 | 2.75 |
| | 30 | 3.68 | 5.42 | 37.3 | 90.7 | 11.0 | 20.3 | 8.36 | 3.55 |
| | 60 | 4.47 | 4.42 | 6.87 | 34.4 | 13.8 | 11.4 | 4.41 | 4.10 |
| | 70 | -- | -- | -- | -- | -- | -- | -- | 3.03 |
| | 80 | -- | -- | -- | -- | -- | 3.37 | -- | -- |
| | 85 | 4.17 | -- | -- | -- | 2.51 | -- | 2.20 | -- |
| | 90 | -- | 3.89 | 2.73 | 3.91 | -- | -- | -- | -- |

[a] Refer to Figure 11.
[b] Dash indicates inaccessible location, impenetrable rocks, etc.

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TABLE 7

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance[a] (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 25 | 1W | Surface | 428 |
| | | 15 | 432 |
| | | 30 | 364 |
| | | 60 | 158 |
| | | 70 | 126 |
| 197 | 15E | Surface | 489 |
| | | 15 | 428 |
| | | 30 | 155 |
| | | 60 | 26.3 |
| | | 90 | 27.3 |
| 205 | 12E | Surface | 303 |
| | | 15 | 417 |
| | | 30 | 372 |
| | | 60 | 77.7 |
| | | 90 | 18.3 |
| 315 | 8E | Surface | 31.5 |
| | | 15 | 32.5 |
| | | 30 | 37.4 |
| | | 60 | 23.9 |
| | | 80 | 12.4 |
| 325 | 5E | Surface | 171 |
| | | 15 | 232 |
| | | 30 | 109 |
| | | 60 | 19.2 |
| | | 90 | 16.9 |
| 401 | 7W | Surface | 136 |
| | | 15 | 140 |
| | | 30 | 56.9 |
| | | 45 | 20.2 |
| 410 | 1E | Surface | 131 |
| | | 15 | 179 |
| | | 30 | 196 |
| | | 60 | 72.7 |
| | | 70 | 61.6 |

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 465 | 1E | Surface | 92.8 |
|  |  | 15 | 91.8 |
|  |  | 30 | 47.8 |
|  |  | 60 | 7.13 |
| 560 | 0E | Surface | 135 |
|  |  | 15 | 243 |
|  |  | 30 | 221 |
|  |  | 60 | 33.2 |
| 585 | 2E | Surface | 138 |
|  |  | 15 | 247 |
|  |  | 25 | 351 |
|  |  | 30 | 322 |
|  |  | 60 | 103 |
| 620 | 0.5E | Surface | 123 |
|  |  | 15 | 201 |
|  |  | 30 | 121 |
|  |  | 60 | 25.0 |
|  |  | 70 | 12.2 |
| 655 | 2W | Surface | 165 |
|  |  | 15 | 259 |
|  |  | 30 | 216 |
|  |  | 60 | 44.9 |
| 665 | 2W | Surface | 135 |
|  |  | 15 | 224 |
|  |  | 30 | 205 |
|  |  | 60 | 26.8 |
| 760 | 1W | Surface | 5.24 |
|  |  | 15 | 8.30 |
|  |  | 30 | 16.7 |
|  |  | 60 | 3.87 |
|  |  | 70 | 1.54 |
| 765 | 3E | Surface | 150 |
|  |  | 15 | 232 |
|  |  | 30 | 395 |
|  |  | 60 | 200 |
|  |  | 90 | 49.0 |

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 765 | 1W | Surface | 64.9 |
| | | 15 | 120 |
| | | 30 | 135 |
| | | 50 | 106 |
| 775 | 1W | Surface | 68.1 |
| | | 15 | 106 |
| | | 30 | 101 |
| | | 60 | 20.0 |
| 790 | 2E | Surface | 119 |
| | | 15 | 140 |
| | | 30 | 53.6 |
| | | 60 | 20.0 |
| | | 70 | 13.8 |
| 889 | 2E | Surface | 53.9 |
| | | 15 | 101 |
| | | 30 | 204 |
| | | 60 | 75.5 |
| 935 | 4W | Surface | 95.9 |
| | | 15 | 141 |
| | | 30 | 76.5 |
| | | 60 | 11.0 |
| | | 70 | 7.42 |
| 989 | 1W | Surface | 94.9 |
| | | 15 | 191 |
| | | 30 | 218 |
| | | 60 | 67.3 |
| 1030 | 3E | Surface | 106 |
| | | 30 | 285 |
| | | 60 | 66.5 |
| | | 70 | 39.8 |
| 1280 | 1W | Surface | 41.1 |
| | | 15 | 42.9 |
| | | 30 | 18.5 |
| | | 60 | 4.22 |

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 1282 | 1W | Surface | 30.3 |
| | | 15 | 37.6 |
| | | 30 | 45.3 |
| | | 60 | 3.13 |
| | | 90 | 2.30 |
| 1325 | 4W | Surface | 15.5 |
| | | 15 | 19.7 |
| | | 30 | 13.1 |
| | | 60 | 3.64 |
| 1340 | 1W | Surface | 38.0 |
| | | 15 | 64.2 |
| | | 30 | 128 |
| | | 60 | 47.0 |
| 1598 | 6W | Surface | 80.4 |
| | | 15 | 122 |
| | | 30 | 299 |
| | | 60 | 117 |
| | | 90 | 7.00 |
| 1665 | 5E | Surface | 83.3 |
| | | 15 | 145 |
| | | 30 | 109 |
| | | 60 | 76.8 |
| | | 90 | 12.3 |
| 1687 | 1E | Surface | 75.8 |
| | | 15 | 107 |
| | | 30 | 181 |
| | | 60 | 64.3 |
| | | 90 | 17.5 |
| 1715 | 1W | Surface | 107 |
| | | 15 | 151 |
| | | 30 | 301 |
| | | 60 | 37.2 |
| | | 90 | 6.67 |

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 1810 | 1W | Surface | 53.3 |
| | | 15 | 49.4 |
| | | 30 | 30.6 |
| | | 60 | 4.49 |
| 1870 | 1E | Surface | 53.9 |
| | | 15 | 87.3 |
| | | 30 | 80.9 |
| | | 60 | 10.1 |
| | | 70 | 6.35 |
| 1880 | 1W | Surface | 27.0 |
| | | 15 | 34.0 |
| | | 30 | 9.40 |
| | | 60 | 9.11 |
| | | 75 | 6.89 |
| 1915 | 1.5W | Surface | 44.1 |
| | | 15 | 58.3 |
| | | 30 | 54.5 |
| | | 60 | 13.0 |
| 1970 | 1E | Surface | 46.3 |
| | | 15 | 63.2 |
| | | 30 | 54.7 |
| | | 60 | 12.7 |
| | | 65 | 10.6 |
| 1975 | 4W | Surface | 51.4 |
| | | 15 | 81.5 |
| | | 30 | 148 |
| | | 60 | 25.2 |
| | | 80 | 6.35 |
| 1980 | 20W | Surface | 89.8 |
| | | 15 | 137 |
| | | 30 | 253 |
| | | 60 | 117 |
| | | 80 | 45.0 |

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

| Downstream Distance (m) | Distance from East (E) or West (W) Bank (m) | Depth (cm) | Total Thorium (Th-232 & Th-228) (pCi/g) |
|---|---|---|---|
| 2006 | 1E | Surface | 109 |
| | | 15 | 138 |
| | | 30 | 205 |
| | | 60 | 103 |
| | | 75 | 54.3 |
| 2030 | 1W | Surface | 46.7 |
| | | 15 | 63.7 |
| | | 30 | 33.7 |
| | | 60 | 3.86 |
| | | 65 | 3.57 |

a Refer to Figures 8, 9, 10, and 11.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

| Downstream Distance (m)[a] | Depth (cm) | Radionuclide Concentration (pCi/g) | | | |
|---|---|---|---|---|---|
| | | Th-232 | Th-228 | Total Thorium (Th-232 & Th-228) | Ra-226 |
| 0 | 0-10 | 27.9 + 1.5[b] | 30.0 + 1.4 | 57.9 | 2.31 + 0.58 |
| | 10-20 | 26.2 + 1.4 | 24.8 + 1.3 | 51.0 | 1.69 + 0.50 |
| | 20-30 | 6.51 + 0.68 | 6.12 + 0.64 | 12.6 | 1.16 + 0.37 |
| | 30-40 | 24.0 + 1.3 | 25.8 + 1.2 | 49.8 | 1.99 + 0.50 |
| 100 | 0-10 | 4.09 + 1.11 | 4.08 + 1.33 | 8.17 | 7.46 + 0.77 |
| | 10-20 | 0.99 + 0.62 | 1.49 + 0.62 | 2.48 | 0.71 + 0.36 |
| | 20-30 | 0.96 + 1.26 | 0.51 + 0.44 | 1.47 | 1.45 + 0.69 |
| 200 | 0-10 | 29.4 + 4.5 | 29.0 + 3.7 | 58.4 | 2.98 + 1.70 |
| | 10-20 | 23.3 + 4.9 | 22.7 + 3.6 | 46.0 | 1.84 + 1.39 |
| | 20-30 | 7.69 + 1.86 | 6.54 + 2.05 | 14.23 | 1.58 + 0.96 |
| | 30-40 | 2.95 + 1.40 | 2.35 + 1.31 | 5.30 | 1.80 + 0.81 |
| | 40-50 | 0.76 + 1.24 | 1.08 + 0.74 | 1.84 | 1.02 + 0.50 |
| | 50-60 | 1.64 + 0.95 | 0.65 + 0.92 | 2.29 | 1.39 + 0.73 |
| 300 | 0-10 | 4.38 + 1.81 | 3.21 + 1.79 | 7.59 | 1.64 + 0.94 |
| | 10-20 | 1.01 + 0.67 | 0.83 + 0.46 | 1.84 | 0.64 + 0.23 |
| | 20-30 | 0.58 + 0.31 | 0.65 + 0.55 | 1.23 | 1.31 + 0.32 |
| 400 | 0-10 | 1.29 + 0.93 | 1.40 + 1.05 | 2.69 | 0.80 + 0.87 |
| | 10-20 | <0.33 | 0.75 + 0.74 | <1.08 | 1.12 + 5.73 |
| | 20-30 | <0.23 | 0.15 + 0.23 | <0.38 | 0.59 + 0.40 |
| 500 | 0-10 | 2.33 + 0.74 | 2.55 + 0.75 | 4.88 | 0.89 + 0.51 |
| | 10-20 | 24.2 + 2.3 | 19.0 + 2.0 | 43.2 | 1.83 + 0.83 |
| | 20-30 | <.33 | 0.57 + 0.47 | <0.90 | 0.76 + 0.54 |

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TABLE 8, cont.

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Radionuclide Concentration (pCi/g) | | | |
|---|---|---|---|---|---|
| | | Th-232 | Th-228 | Total Thorium (Th-232 & Th-228) | Ra-226 |
| 600 | 0-10 | 44.4 + 3.5 | 39.6 + 3.1 | 84.0 | 1.45 + 1.21 |
| | 10-20 | 9.96 + 1.52 | 8.13 + 1.50 | 18.1 | 0.70 + 0.61 |
| 700 | 0-10 | 1.56 + 0.71 | 1.47 + 0.55 | 3.03 | 0.68 + 0.50 |
| | 10-20 | 0.53 + 0.68 | 0.51 + 0.34 | 1.04 | 0.46 + 0.35 |
| | 20-30 | <1.81 | 1.59 + 0.64 | <3.40 | 0.61 + 0.27 |
| 800 | 0-10 | 12.2 + 2.5 | 13.8 + 1.9 | 26.0 | 1.43 + 0.80 |
| | 10-20 . | 11.1 + 1.7 | 9.99 + 1.14 | 21.1 | 1.16 + 0.53 |
| | 20-30 | 1.80 + 0.77 | 2.83 + 0.81 | 4.63 | 0.87 + 0.49 |
| 900 | 0-10 | 1.60 + 0.63 | 1.49 + 0.57 | 3.09 | 1.09 + 0.60 |
| | 10-20 | 0.21 + 0.30 | 0.84 + 0.49 | 1.05 | 0.67 + 0.28 |
| | 20-30 | 0.57 + 0.41 | 0.44 + 0.45 | 1.01 | 0.59 + 0.24 |
| 1000 | 0-10 | 1.18 + 1.36 | 1.78 + 1.14 | 2.96 | 2.08 + 0.86 |
| | 10-20 | 5.29 + 1.69 | 4.38 + 1.54 | 9.67 | 1.68 + 1.50 |
| | 20-30 | 1.16 + 0.61 | 1.29 + 0.41 | 2.45 | 0.65 + 0.34 |
| 1100 | 0-10 | 6.38 + 1.54 | 6.18 + 1.40 | 12.6 | 1.06 + 0.54 |
| | 10-20 | 1.33 + 0.56 | 1.15 + 0.47 | 2.48 | 0.90 + 0.30 |
| | 20-30 | 0.87 + 0.36 | 0.52 + 0.43 | 1.39 | 0.64 + 0.29 |
| 1250 | 0-10 | 21.5 + 2.1 | 18.1 + 1.8 | 39.6 | 1.34 + 0.76 |
| | 10-20 | 11.9 + 1.9 | 10.0 + 1.7 | 21.9 | 1.41 + 0.86 |
| | 20-30 | 2.29 + 0.91 | 2.19 + 0.72 | 4.48 | 0.68 + 0.38 |

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

| Downstream Distance (m) | Depth (cm) | Radionuclide Concentration (pCi/g) | | | |
|---|---|---|---|---|---|
| | | Th-232 | Th-228 | Total Thorium (Th-232 & Th-228) | Ra-226 |
| 1350 | 0-10 | 5.96 + 1.42 | 5.04 + 0.88 | 11.0 | 0.56 + 0.55 |
| | 10-20 | 5.32 + 1.43 | 4.29 + 1.29 | 9.61 | 1.28 + 0.78 |
| | 20-30 | 5.09 + 3.18 | 4.71 + 1.52 | 9.80 | 0.75 + 1.75 |
| 1450 | 0-10 | <0.45 | 0.95 + 0.37 | <1.40 | 0.84 + 0.72 |
| | 10-20 | 0.85 + 0.91 | 1.01 + 0.55 | 1.86 | 1.73 + 0.64 |
| | 20-30 | 0.46 + 0.68 | 0.54 + 0.64 | 1.00 | 1.13 + 0.61 |
| 1650 | 0-10 | 3.77 + 0.76 | 3.27 + 0.6 | 7.04 | 1.05 + 0.29 |
| | 10-20 | 0.60 + 0.34 | 0.27 + 0.34 | 0.87 | 0.62 + 0.21 |
| | 20-30 | 0.65 + 0.52 | 1.48 + 0.48 | 2.13 | 0.64 + 0.38 |
| 1750 | 0-10 | 2.39 + 0.87 | 1.91 + 0.54 | 4.30 | 0.89 + 0.55 |
| | 10-20 | 1.28 + 0.57 | 0.66 + 0.49 | 1.94 | 1.17 + 0.37 |
| | 20-30 | 1.00 + 0.49 | 0.98 + 0.52 | 1.98 | 0.94 + 0.50 |
| 1850 | 0-10 | 66.0 + 4.2 | 49.8 + 3.7 | 116 | 2.60 + 1.44 |
| | 10-20 | 71.7 + 4.2 | 59.1 + 3.8 | 131 | 2.66 + 1.69 |
| | 20-30 | 4.13 + 0.94 | 3.06 + 0.62 | 7.19 | 0.77 + 0.32 |
| 1950 | 0-10 | 0.64 + 0.40 | 0.67 + 0.48 | 1.31 | 0.39 + 0.27 |
| | 10-20 | 0.43 + 0.42 | <0.07 | <0.50 | 0.70 + 0.44 |
| | 20-30 | 0.44 + 0.65 | 0.33 + 0.56 | 0.77 | 0.37 + 0.25 |
| 2050 | 0-10 | 4.40 + 1.04 | 3.69 + 0.91 | 8.09 | 0.92 + 0.61 |
| | 10-20 | 1.13 + 0.83 | 1.17 + 0.51 | 2.30 | 0.75 + 0.36 |
| | 20-30 | 0.69 + 0.46 | 0.50 + 0.62 | 1.19 | 0.53 + 0.28 |

[a] Refer to Figure 12.
[b] Errors are $2\sigma$ based on counting statistics.

TABLE 9

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM THE DUPAGE RIVER

| Upstream or Downstream Distance (m)[a] | Depth (cm) | Radionuclide Concentrations (pCi/g) | | | |
|---|---|---|---|---|---|
| | | Th-232 | Th-228 | Total Thorium (Th-232 & Th-228) | Ra-226 |
| **Upstream:** | | | | | |
| 200 | 0-10 | 0.51 + 0.31[b] | 0.70 + 0.33 | 1.21 | 0.57 + 0.36 |
| | 10-20 | 1.06 + 0.50 | 1.18 + 0.43 | 2.24 | 0.40 + 0.26 |
| | 20-30 | <0.18 | <0.16 | <0.34 | 0.54 + 0.27 |
| 100 | 0-10 | <0.45 | 0.70 + 0.47 | <1.15 | <0.39 |
| | 10-20 | 0.58 + 0.49 | 0.40 + 0.42 | 0.98 | 0.63 + 0.36 |
| | 20-30 | <0.31 | 1.16 + 0.20 | <1.47 | 0.72 + 0.37 |
| 0 | 0-10 | 1.23 + 0.50 | 0.71 + 0.43 | 1.94 | 0.50 + 0.28 |
| | 10-20 | 0.71 + 0.49 | 0.53 + 0.42 | 1.24 | 0.83 + 0.29 |
| | 20-30 | 0.58 + 0.36 | 0.81 + 0.35 | 1.39 | 0.36 + 0.24 |
| **Downstream:** | | | | | |
| 100 | 0-10 | 15.2 + 1.9 | 12.0 + 1.60 | 27.2 | 1.39 + 0.84 |
| | 10-20 | 0.38 + 0.37 | 0.65 + 0.29 | 1.03 | 0.67 + 0.32 |
| | 20-30 | 0.41 + 0.61 | <0.08 | <0.49 | 0.29 + 0.51 |
| 200 | 0-10 | 1.83 + 0.94 | 2.84 + 0.82 | 4.67 | 0.48 + 0.27 |
| | 10-20 | 1.22 + 0.46 | 1.07 + 0.35 | 1.29 | 0.57 + 0.26 |
| | 20-30 | 0.33 + 0.36 | 0.26 + 0.42 | 0.59 | 0.38 + 0.18 |

[a] Refer to Figure 12.
[b] Errors are 2σ based on counting statistics.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN WELL WATER SAMPLES

| Sample Location[a] | Radionuclide Concentration (pCi/l) | |
|---|---|---|
| | Gross Alpha | Gross Beta |
| 1 | <1.42 | <2.25 |
| 2 | <1.35 | 4.29 + 3.37[b] |
| 3 | <1.37 | 2.58 + 3.29 |
| 4 | <1.44 | <2.26 |
| 5 | 1.48 + 2.13 | 4.98 + 3.41 |
| 6 | <1.33 | 4.62 + 3.38 |

[a] All samples were collected from Edgewood Walk. Locations are not identified on a figure.

[b] Errors are 2$\sigma$ based on counting statistics.

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3. Letter, D. Kee (EPA) to A.B. Davis (NRC), re. EPA analysis of soil, sediment, and water from Kress Creek, January 29, 1981.

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APPENDIX A

GLOSSARY OF TERMS

Activation: The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.

Activity: Radioactivity, the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an unstable nuclide. As a result of this emission, the radioactive material is converted (or decays) into a different nuclide (daughter), which may or may not be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) nuclide is formed.

Aerial survey: A search for sources of radiation by means of sensitive instruments mounted in a helicopter or airplane. Generally, the instrumentation records the intensity, location, and spectral analysis of the radiation.

Alpha particle: A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, and hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, and can be stopped by a sheet of paper.

Background radiation: The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements. It is also called natural radiation. The term may also mean radiation that is unrelated to a specific experiment. Levels vary, depending on location.

Baseline concentration: The concentration of a given substance typically encountered in the area under consideration, i.e. the normal or naturally occurring level.

Beta particle: An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Contamination: Undesired radioactive materials that have been deposited on surfaces, are internally ingrained into structures or equipment, or that have been mixed with another material.

Curie:

A special unit of activity. One curie equals $3.7 \times 10^{10}$ nuclear disintegrations per second. Several fractions of the curie are in common usage:

-- Millicurie - one thousandth of a curie. Abbreviated as mCi.

-- Microcurie - one millionth of a curie. Abbreviated as $\mu$Ci.

-- Nanocurie - one billionth of a curie. Abbreviated as nCi.

-- Picocurie - one trillionth of a curie. Abbreviated as pCi.

Daughter:

The product of radioactive decay of a nuclide. (also see Parent).

Decay, radioactive:

The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of original radioactive nuclides in a sample. It involves the emission from the nucleus of alpha particles, beta particles, or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.

Decontamination:

Those activities employed to reduce the levels of contamination.

Dose:

A measure of the quantity of radiation absorbed in a unit mass of a medium. The unit of dose is the rad.

Dose rate:

The radiation dose delivered per unit time and measured, for example, in rads per hours.

Exposure:

A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

Exposure rate:

The radiation exposure per unit time. Measured, for example, in roentgens per hour.

Gamma radiation:

High-energy, short-wave length electromagnetic radiation of nuclear origin (radioactive decay). Gamma rays are

the most penetrating of the three common types of radiation.

Half-life:          The time in which half the atoms of a particular radioactive sustance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.

Microrad (μrad):    A submultiple of the rad, equal to one-millionth of a rad. (see rad).

Microroentgen
(μR):               A submultiple of the roentgen, equal to one-millionth of a roentgen. (see roentgen).

Millirem (mrem):    A submultiple of the rem, equal to one-thousandth of a rem. (see rem).

Natural uranium:    Uranium as found in nature, containing 0.7 percent of uranium-235, 99.3 percent of uranium-238. It is also called normal uranium.

Natural thorium:    Thorium as found in nature. Natural thorium contains equal activity level of thorium-232 and thorium-228.

Parent:             A radionuclide which disintegrates or decays to produce another nuclide which is also radioactive. This second radionuclide is known as the daughter product.

Picocurie (pCi):    One-trillionth ($10^{-12}$) of a curie.

Rad:                The unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joules/kilogram of absorbing material.

Radiation:          Energetic nuclear particles including neutrons, alpha particles, beta particles, x-rays, and gamma rays (nuclear physics). Also includes electromagnetic waves (radiation) of any origin.

Radioactivity:      The property of certain nuclides of spontaneously emitting particles, or gamma radiation. Often shortened to "activity."

Radionuclide:       A general term applicable to any radioactive form of the elements, a radioactive nuclide.

Radium (Ra):        A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite, and other minerals; the uranium decay﹥ to radium in a series

of alpha and beta emissions. By virtue of being an alpha- and gamma-emitter, radium is used as a source of illuminescence and as a radiation source in medicine and radiography. The isotope of radium with an atomic weight of 228 is found in the thorium decay series.

Radon (Rn): The heaviest element of the noble gases, produced as a gaseous emanation from the radioactive decay of radium. Its atomic number is 86. All isotopes are radioactive. Rn-222 is an isotope with a half-life of 3.82 days.

Rare earths: A group of 15 chemically similar metallic elements, including elements 57 through 71 on the Periodic Table of the Elements, also known as the Lanthanide Series.

Rem: The unit of ionizing radiation that produces the same biological damage to man as a unit of absorbed dose (1 roentgen) of high voltage x-rays.

Roentgen (R): A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions.

Secular
Equilibrium: The state which prevails when the rate of formation of a radioactive material equals the material's rate of decay. Although, by theory, this condition is never completely achieved, it is essentially established in the thorium decay series as it occurs in nature.

Survey: An evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions.

Thorium (Th): A naturally occurring radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232.

Thorium series: The series (sequence) of nuclides resulting from the radioactive decay of thorium-232. Many man-made nuclides decay into this sequence. The end product of the sequence in nature is lead-208.

Uranium (U): A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natual uranium) and uranium-238 (99.3 percent of natural uranium). Natural uranium also includes a minute amount of uranium-234.

Uranium series:  The series (sequence) of nuclides resulting from the radioactive decay of uranium-238.  The end product of the series is lead-206.

# EXPLANATION OF SYMBOLS AND UNITS

| Symbols | Unit | English Equivalents |
|---|---|---|
| cm | centimeter (x $10^{-2}$ meters) | 0.394 inches |
| g | gram | 0.032 ounces |
| h | hour | ----- |
| kg | kilogram (x $10^{3}$ grams) | 2.2 pounds |
| km | kilometer (x $10^{3}$ meters) | 0.622 miles |
| l | liter | 0.264 gallons |
| m | meter | 3.28 feet |
| ml | milliliter (x $10^{-3}$ liters) | 0.061 cubic in. |
| mrem | millirem (x $10^{-3}$ rem) | ----- |
| pCi | picocurie (x $10^{-12}$ curies) | ----- |
| Ra | Radium | ----- |
| U | Uranium | ----- |
| Th | Thorium | ----- |
| μCi | microcurie (x $10^{-6}$ curies) | ----- |
| μrad | microrad (x $10^{-6}$ rads) | ---- |
| μR | microroentgen (x $10^{-6}$ roentgens) | ---- |

APPENDIX B

THORIUM AND URANIUM DECAY TABLES

## Thorium Decay Series

| Parent | Half-Life | Major Decay Products | Daughter |
|---|---|---|---|
| Thorium-232 | 14 billion years | alpha | Radium-228 |
| Radium-228 | 5.8 years | beta | Actinium-228 |
| Actinium-228 | 6.13 hours | beta, gamma | Thorium-228 |
| Thorium-228 | 1.91 years | alpha | Radium-224 |
| Radium-224 | 3.64 days | alpha | Radon-220 |
| Radon-220 | 55 seconds | alpha | Polonium-216 |
| Polonium-216 | 0.15 seconds | alpha | Lead-212 |
| Lead-212 | 10.6 hours | beta, gamma | Bismuth-212 |
| Bismuth-212 | 60.6 minutes | alpha (1/3)* beta (2/3)* | Thallium-208 Polonium-212 |
| Thallium-208 | 3.1 minutes | beta, gamma | Lead-208 |
| Polonium-212 | 0.0000003 seconds | alpha | Lead-208 |
| Lead-208 | stable | none | none |

* Two decay modes are possible for Bismuth-212.

## Uranium Decay Series

| Parent | Half-Life | Major Decay Products | Daughter |
|--------|-----------|----------------------|----------|
| Uranium-238 | 4.5 billion years | alpha | Thorium-234 |
| Thorium-234 | 24 days | beta, gamma | Protactinium-234 |
| Protactinium-234 | 1.2 minutes | beta, gamma | Uranium-234 |
| Uranium-234 | 250,000 years | alpha | Thorium-230 |
| Thorium-230 | 80,000 years | alpha | Radium-226 |
| Radium-226 | 1,600 years | alpha | Radon-222 |
| Radon-222 | 3.8 days | alpha | Polonium-218 |
| Polonium-218 | 3 minutes | alpha | Lead-214 |
| Lead-214 | 27 minutes | beta, gamma | Bismuth-214 |
| Bismuth-214 | 20 minutes | beta, gamma | Polonium-214 |
| Polonium-214 | 0.0002 seconds | alpha | Lead-210 |
| Lead-210 | 22 years | beta | Bismuth-210 |
| Bismuth-210 | 5 days | beta | Polonium-210 |
| Polonium-210 | 140 days | alpha | Lead-206 |
| Lead-206 | stable | none | none |

APPENDIX C

MAJOR ANALYTICAL EQUIPMENT

APPENDIX C

Major Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A.   Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter
Model PRS-1
Beta-Gamma "Pancake" Probe, Model HP-260
(Eberline Instrument, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
Scintillation Probe, Model 489-55
(Victoreen, Inc., Cleveland, OH)

Pressurized Ionization Chamber (PIC)
Model RSS-111
(Reuter Stokes, Cleveland, OH)

Ludlum Ratemeter-Scaler
Model 2200
(Ludlum Measurements Inc., Sweetwater, TX)

B.   Laboratory Analysis

Ge(Li) Detector
Model LGCC2220SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

High-Purity Germanium Detector
Model GMX-23195-S, 23% efficiency
(EG&G ORTEC, Oak Ridge, TN)

Used in conjunction with:
Lead Shield, G-16
(Gamma Products Inc., Palos Hills, IL)

Pulse Height Analyzer, ND680
Model 88-0629
(Nuclear Data, Inc., Schaumburg, IL)

Low Background Alpha-Beta Counter
Model LB5100-2080
(Tennelec, Inc., Oak Ridge, TN)

25 mg Californium-252 Source with Flexo-Rabbit
Pneumatic Transfer System
(Reactor Experiments, Inc., San Carlos, CA)

Multichannel Analyzer
Model TN-7200
(Tracor Northern, Middleton, WI)

APPENDIX D

ANALYTICAL PROCEDURES

Analytical Procedures

## Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using an Eberline PRM-6 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. A graph of count rate (cpm) vs. exposure rate ($\mu$R/h) was developed by comparing the response of the scintillation detector with that of a Reuter Stokes Model RSS-111 pressurized ionization chamber at several locations along Kress Creek. This plot was used to convert the meter readings to exposure rates.

## Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal" Model PRS-1 portable ratemeters with Model HP-260 G-M probes. Dose rates ($\mu$rad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a natural thorium source.

## Soil and Sediment Sample Analysis

Soil samples were sifted to remove rocks (the fraction removed constituted <5% of the total), dried at 120° C, finely ground, mixed, and a portion placed in a 0.5 liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and typically ranged from 500 to 800 g of soil. Sediment samples were treated identically except that they were placed in 0.2 liter jars and typically weighed 100 g. Net weights were determined and the samples counted using either a Ge(Li) detector (Princeton Gamma Tech) or a high purity germanium detector (EG&G ORTEC) coupled to a Nuclear Data model ND 680 pulse height analyzer. The following energy peaks were used for determination of the radionuclides of concern:

Th-232  - 0.911 MeV from Ac-228 (secular equilibrium assumed)

Th-228  - 0.583 MeV from Tl-208     "          "          "

Ra-226  - 0.609 MeV from Bi-214 (corrected for equilibrium conditions)

U-238   - 1.001 MeV from Pa-234m    "          "          "

        or 0.093 MeV from Th-234  "          "          "


Peak identification and concentration calculations were provided by computer analyses.


Selected samples for which gamma spectrometry indicated detectable levels of uranium were subsequently analyzed for U-238 by neutron activation. Approximately 15-20 g of soil were irradiated for 15 minutes in a neutron flux of $10^8$ n/cm$^2$/sec. After a one minute wait time, the U-239 peak (74.6 keV) was counted for 10 minutes and the U-238 concentration calculated.


## Borehole Logging and Calculation of Thorium Concentrations


Borehole gamma radiation measurements were made using a Victoreen Model 489-55 gamma scintillation probe connected to a Ludlum Model 2200 portable scaler. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the shield in the region of the scintillation detector. Measurements were typically performed at depths of 0, 15, 30, 60, and 90 cm.


The thorium, uranium, and radium ratios were sufficiently constant to allow the estimation of the total thorium concentrations in soil from the borehole logging data. Soil samples were taken from approximately 15% of the boreholes and analyzed for total thorium (Th-228 and Th-232) by gamma spectrometry. The total thorium concentrations and the gamma radiation levels measured at the points of sampling were used to generate a third order logarithmic polynomial equation. This equation was then used to convert gamma levels in the boreholes into pCi/g of thorium in soil.


The data points and the curve generated are presented in the accompanying graph. It should be noted that the curve has a tendency to overestimate the
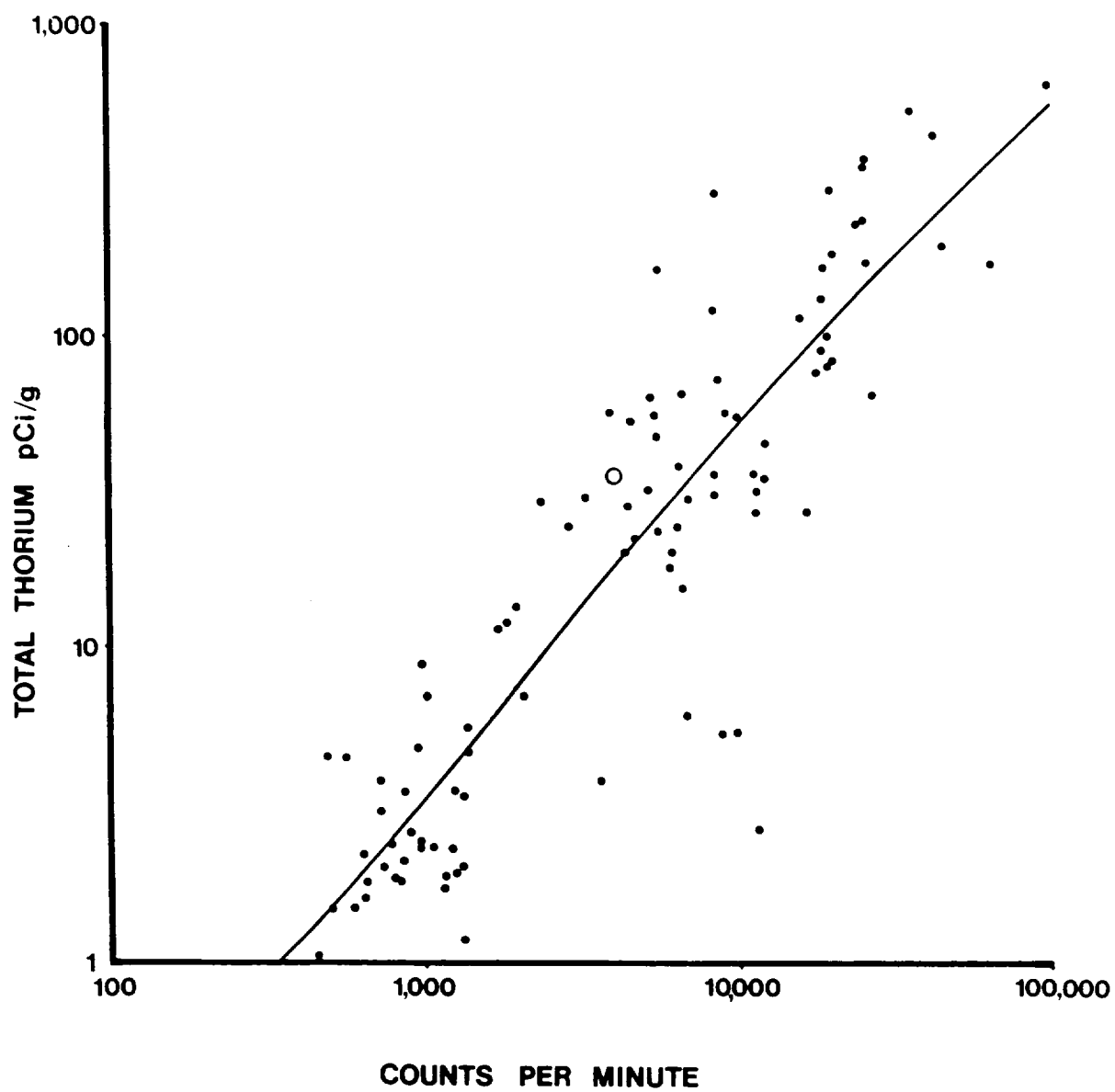
FIGURE 1. Direct Radiation Levels in Boreholes (CPM) Versus Total
Thorium Concentration (pCi/g) in Soil.

thorium concentrations at the low end. The open circle in the figure indicates a measurement in a monazite sand standard.

## Water Samples

Water samples were rough filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by filtration through 0.45 μm pore size membrane filters. The filters, together with attached solids, were discarded, and the filtrate was acidified by the addition of 20 ml of concentrated nitric acid.

## Gross Alpha and Gross Beta Analysis

Fifty milliliters of each sample was evaporated to dryness and counted on a Tennelec Model LB5100 low background proportional counter.

## Errors and Detection Limits

The errors associated with the analytical data presented in the tables of this report, represent the 95% (2σ) confidence levels for that data. These errors were calculated, based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 2σ statistical deviation of the background count, the sample concentration was reported as less than the minimum detectable activity (<MDA). This means that the radionuclide was not present, to the best of our ability to measure it, utilizing the analytical techniques described in this appendix. Because of variations in background levels, caused by other constituants in the samples, the MDAs for specific radionuclides differ from sample to sample.

## Calibration and Quality Assurance

Laboratory and analytical instruments are calibrated using NBS-traceable standards. Portable survey instruments for exposure rate and dose rate measurements are calibrated by comparison of their responses to those of other instruments having NBS-traceable calibration. Field comparisons or comparisons using samples typical of the area are used to develop these calibrations.

Quality control procedures on all instruments included daily background and check-source measurements to confirm lack of malfunctions and nonstatistical deviations in equipment. The ORAU laboratory participates in the EPA Quality Assurance Program.